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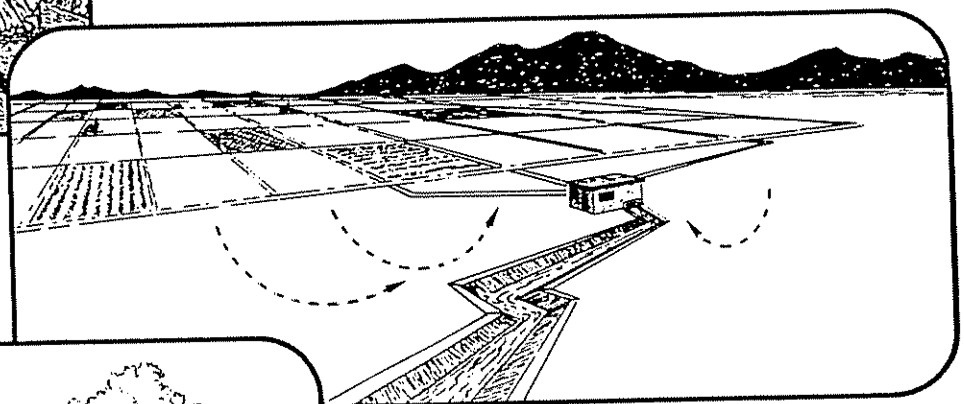
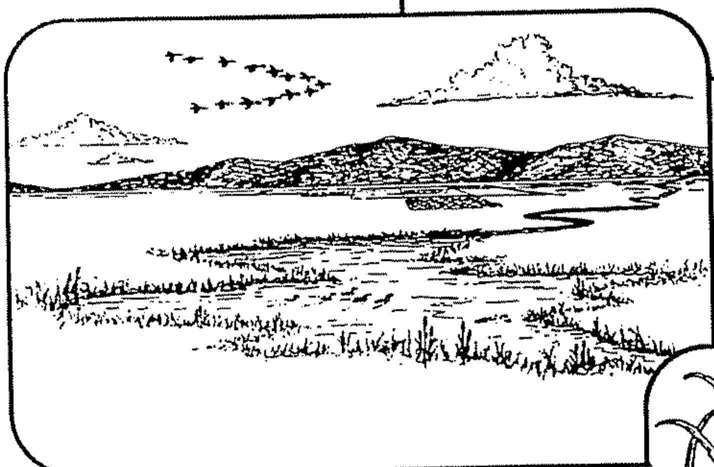
Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Salton Sea Area, California, 1986-87





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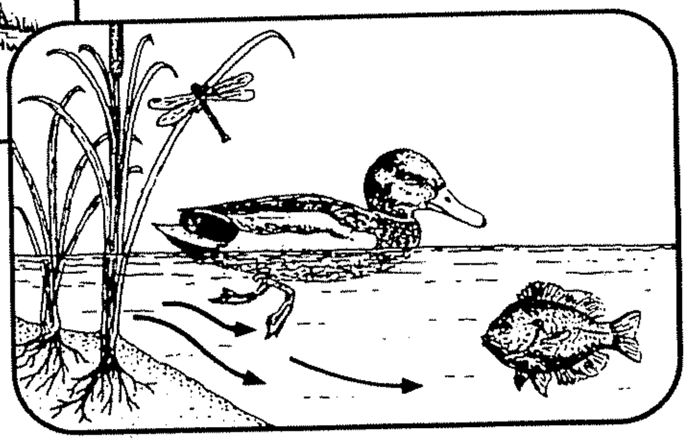

U.S. Geological Survey
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U.S. Bureau of Reclamation

RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE SALTON SEA AREA, CALIFORNIA, 1986-87

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U.S. FISH AND WILDLIFE SERVICE

U.S. GEOLOGICAL SURVEY

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U.S. GEOLOGICAL SURVEY

U.S. FISH AND WILDLIFE SERVICE

U.S. BUREAU OF RECLAMATION

7414-14

Sacramento, California
1990

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below.

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per annum
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer

ABBREVIATIONS

cm, centimeter
g/kg, gram per kilogram
mg/kg, milligram per kilogram
mg/L, milligram per liter
μg/g, microgram per gram
μg/L, microgram per liter
μm, micrometer (3.937×10^{-5} inches)
μS/cm, microsiemen per centimeter at 25 °Celsius
pCi/L, picocurie per liter
ppb, parts per billion (dry weight)
ppm, parts per million (dry weight)

DDD, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethane
DDE, 1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene
DDT, 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethylene
NCBP, National Contaminant Biomonitoring Program
NWR, National Wildlife Refuge
PCB, Polychlorinated biphenyls

DEFINITION OF TERMS

Sea Level.--In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Water Year.--The water year starts October 1 and ends September 30; it is designated by the calendar year in which it ends.

Trade Names.--The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE SALTON SEA AREA, CALIFORNIA, 1986-87

By James G. Setmire, John C. Wolfe, *and* Richard K. Stroud

ABSTRACT

Water, bottom sediment, and biota were sampled during 1986-87 in the Salton Sea area to determine concentrations of trace elements and pesticides as part of the Department of Interior Irrigation Drainage Program. The sampling sites (12 water, 15 bottom sediment, and 5 biota) were located in the Coachella and Imperial Valleys. The focus of sampling was to determine if contaminants in irrigation drainage from Department of the Interior-sponsored irrigation projects have caused or have the potential to cause substantial harmful effects to humans, fish, or wildlife, or to reduce the suitability of water for beneficial uses. Results indicate that selenium is the major element of concern. Elevated concentrations of selenium in water were restricted to tile-drain effluent. The maximum selenium concentration of 300 micrograms per liter was detected in tile drain 6, and the minimum concentration of 1 microgram per liter was detected in a composite sample of Salton Sea water. The median selenium concentration was 19 micrograms per liter. In contrast to the water, the highest bottom-sediment selenium concentration of 3.3 milligrams per kilogram was in a composite sample from the Salton Sea.

Concentrations of boron were elevated in tile-drain samples throughout the Imperial Valley. Boron concentrations were at levels in migratory waterfowl that could cause reproductive impairment. Elevated concentrations of chromium, nickel, and zinc were detected in the bottom sediment of the Whitewater River, but they were not associated with irrigation drainage.

Organochlorine pesticide residues were detected in bottom sediment throughout the study area at levels approaching those measured more than 10 years ago. More detailed studies will be needed to determine if these residues are affecting the waterfowl.

In biota, selenium concentrations in tilapia and corvina ranged from 3.5 to 20 micrograms per gram dry weight; the mean concentration, 10.5 micrograms per gram, exceeds the 8.0-microgram-per-gram (dry weight) safe level for human consumption of fish. In waterfowl, selenium was detected in livers at concentrations as high as 27 and 42 micrograms per gram in black-necked stilts and cormorants, respectively. Selenium levels in waterfowl and fish approach levels of concern, but, to date, no studies have been done in the Salton Sea area to determine if selenium has caused adverse biological effects such as observed in other areas contaminated by selenium from agricultural drainwater.

Mercury levels in waterfowl also were elevated. Concentrations in livers of cormorants and great blue herons ranged from 7.6 to 49 micrograms per gram. Shoveler ducks also had relatively high levels of mercury; concentrations in livers ranged from 2.2 to 11 micrograms per gram. These far-ranging and migratory birds likely accumulate the mercury outside the Salton Sea basin.

INTRODUCTION

Background

During the past several years, there has been increasing concern about the quality of irrigation drainage--that is, both surface and subsurface water draining irrigated land--and its potential effects on human health, fish, and wildlife. Elevated concentrations of selenium have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley in California. In 1983, incidences of mortality, developmental abnormalities, and reproductive failures among waterfowl and shorebirds were documented by the U.S. Fish and Wildlife Service at the Kesterson National Wildlife Refuge (Kesterson NWR) in the western San Joaquin Valley, where irrigation drainage was impounded in Kesterson Reservoir.[1] In addition, potentially toxic trace elements and pesticide residues have been detected in other areas in the Western States that receive irrigation drainage.

Because of concerns expressed by the U.S. Congress, the Department of the Interior started a program in late 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the Western States. In October 1985, an interbureau group known as the "Task Group on Irrigation Drainage" was formed within the Department. The Task Group subsequently prepared a comprehensive plan for reviewing irrigation-drainage concerns for which the Interior Department may have responsibility.

Initially, the Task Group identified 19 locations in 13 States that warranted reconnaissance-level field investigations. These locations relate to three specific areas of Interior Department responsibilities: (1) irrigation or drainage facilities constructed or managed by the Interior Department, (2) national wildlife refuges that receive irrigation drainage, and (3) other migratory-bird or endangered-species management areas that receive water from Department-funded projects.

Nine of the 19 locations were selected for reconnaissance studies that began in 1986. The nine areas are:

Arizona-California:	Lower Colorado-Gila River Valley area
California:	Salton Sea area
	Tulare Lake Bed area
Montana:	Sun River Reclamation Project area
	Milk River Reclamation Project area
Nevada:	Stillwater Wildlife Management area
Texas:	Lower Rio Grande-Laguna Atascosa National Wildlife Refuge area
Utah:	Middle Green River basin area
Wyoming:	Kendrick Reclamation Project area

Each reconnaissance investigation was conducted by interbureau field teams composed of a scientist from the U.S. Geological Survey as team leader and additional U.S. Geological Survey, U.S. Fish and Wildlife Service, and U.S. Bureau of Reclamation scientists representing several different disciplines. The studies were directed toward determining whether irrigation drainage (1) has caused or has the potential to cause significant harmful effects on human health or on fish and wildlife, or (2) may reduce the suitability of water for beneficial uses. This report describes the results of the Salton Sea area reconnaissance investigation.

The Salton Sea area is in the southeastern desert region of California and includes the Coachella and Imperial Valleys (fig. 1). This study focused primarily on the Imperial Valley because of its extensively developed irrigated agriculture, and because drainage from the Imperial Valley discharges directly into the Salton Sea National Wildlife Refuge.

Agriculture in the Salton Sea area is dependent on water from the Colorado River for irrigation. The diversion of this water to the Imperial and Coachella Valleys via the All-American Canal is regulated by the

[1]Kesterson Reservoir occupies only 1,283 of 5,900 acres within Kesterson National Wildlife Refuge. Data and observations from Kesterson National Wildlife Refuge referred to throughout this report usually were obtained from the small Kesterson Reservoir, which is part of the refuge.

U.S. Bureau of Reclamation. Most soils in the major growing areas of the Imperial and Coachella Valleys are lacustrine deposits, which, under the influence of irrigated agriculture, have formed partly perched water tables. The presence of water close to land surface and the accumulation of salts from evaporation of water in the soils have required installation of underground tile drains in fields throughout the Imperial Valley. The drains relieve waterlogging and salt buildup, thereby maintaining a successful agricultural environment. Water from these tile drains eventually discharges into the Salton Sea near the Salton Sea National Wildlife Refuge. Dissolved trace minerals (leached from the soil column) in the drainwater have been recognized as being potentially harmful to human health and to various wildlife species in other irrigation projects such as Kesterson Reservoir in Kesterson National Wildlife Refuge. Determining the composition of drainwater and its effects on receiving-water quality and on biota were the main objectives of this irrigation-drainage study.

Analysis of available data from the Salton Sea area indicated that contaminants from irrigation drainage in the Imperial and Coachella Valleys are adversely affecting the water quality and the health of the fish and wildlife using the Salton Sea National Wildlife Refuge. Existing and potential effects include:

- High levels of selenium in edible portions of fish in the Salton Sea. An Imperial County health advisory has been issued limiting the consumption of fish caught in the Salton Sea to 4 ounces per 2-week period.

- Selenium contamination of waterfowl in the Salton Sea area may reach levels that have been associated with reproductive failure.

- Organochlorine pesticide residues in rivers and drains may pose a threat to reproductive success of waterfowl.

In addition to these concerns, (1) the Salton Sea is the terminus of three major rivers conveying over 1 million acre-ft/yr of irrigation return water; (2) the Salton Sea has few other sources of freshwater and has no outlet; (3) the salinity of the Salton Sea has increased over the past 80 years due to evaporation produced by the high average annual temperatures over the large surface area of the Salton Sea; and (4) the Salton Sea National Wildlife Refuge supports the most diverse bird populations of any national wildlife refuge and is the breeding ground for several endangered species. As a result, there is a high level of concern about the water quality of the Salton Sea and the future of its wildlife.

Purpose and Scope

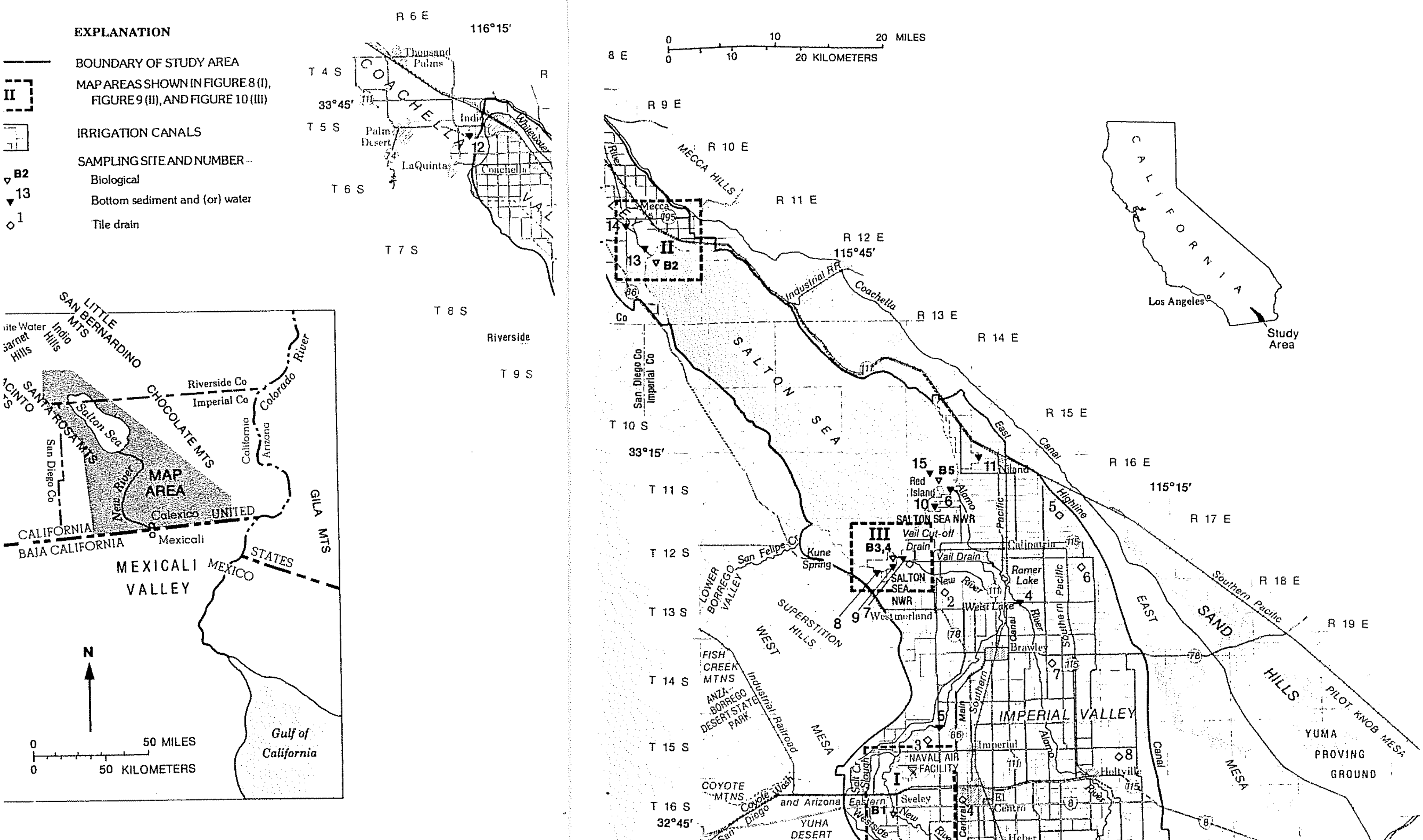
This report presents results of a study to determine the impact of irrigation drainage from water supplied by the U.S. Bureau of Reclamation on downstream uses, especially the effect on fauna of the Salton Sea National Wildlife Refuge. The specific objectives of the study were to:

(1) Determine concentrations of selected pesticides and trace elements in the water and bottom sediments of the Salton Sea and of streams and drains conveying agricultural effluent.

(2) Determine concentrations of selected pesticides and trace elements in the wildlife and fish of the Salton Sea National Wildlife Refuge.

(3) Evaluate available data to determine if elevated levels of contaminants are the result of agricultural pollution.

A reconnaissance sampling of the study area for trace elements and pesticides in water and bottom sediments was done in August 1986 by the U.S. Geological Survey. Wildlife sampling for selected pesticides and trace elements (birds and fish of the Salton Sea National Wildlife Refuge) was performed by the U.S. Fish and Wildlife Service. This sampling was completed in April 1987. In addition, existing data--particularly data on the areal and temporal distribution of pesticides in agricultural drains in the southeastern desert of California (Eccles, 1979) and trace-element data collected by the California Regional Water Quality Control Board from the Salton Sea area--were evaluated and compared to information collected in the reconnaissance study.



EXPLANATION
BOUNDARY OF STUDY AREA
MAP AREAS SHOWN IN FIGURE 8 (I), FIGURE 9 (II), AND FIGURE 10 (III)
IRRIGATION CANALS
SAMPLING SITE AND NUMBER--
Biological
Bottom sediment and (or) water
Tile drain
B2
13
1
II
R 6 E
116°15′
Thousand Palms
T 4 S
COACHELLA VALLEY
33°45′
T 5 S
Palm Desert
Indio
Whitewater
LaQuinta
Coachella
12
T 6 S
T 7 S
T 8 S
Riverside
T 9 S
LITTLE SAN BERNARDINO MTS
Indio Hills
Garnet Hills
SANTA ROSA MTS
Riverside Co
Imperial Co
CHOCOLATE MTS
Colorado River
California
Arizona
San Diego Co
Salton Sea
New River
MAP AREA
Calexico
UNITED
CALIFORNIA
BAJA CALIFORNIA
Mexicali
GILA MTS
STATES
MEXICO
MEXICALI VALLEY
N
0
50 MILES
50 KILOMETERS
Gulf of California
0
10
20 MILES
20 KILOMETERS
8 E
R 9 E
R 10 E
MECCA HILLS
R 11 E
Mecca
14
13
B2
R 12 E
115°45′
Industrial RR
Coachella
R 13 E
R 14 E
SALTON SEA
San Diego Co
Imperial Co
T 10 S
33°15′
R 15 E
East
Canal
R 16 E
15
B5
11
Niland
Red Island
10
6
Alamo
5
Highline
115°15′
SALTON SEA NWR
R 17 E
III
B3,4
Vail Cut-off Drain
Vail Drain
Calipatria
Pacific
T 11 S
T 12 S
San Felipe Cr
Kune Spring
SALTON SEA NWR
New River
Ramer Lake
6
Southern Pacific
R 18 E
LOWER BORREGO VALLEY
SUPERSTITION HILLS
8
9
7
Westmorland
2
West Lake
4
River
EAST
SAND
R 19 E
T 13 S
WEST
Brawley
7
78
115
FISH CREEK MTNS
ANZA-BORREGO DESERT STATE PARK
Industrial Railroad
T 14 S
MESA
IMPERIAL VALLEY
HILLS
PILOT KNOB MESA
Main
Southern
Alamo
5
3
T 15 S
NAVAL AIR FACILITY
Imperial
8
Holtville
Canal
YUMA PROVING GROUND
MESA
COYOTE MTNS
Coyote Wash
I
Salt Cr Slough
and Arizona
Eastern
Seeley
El Centro
Central
T 16 S
32°45′
San Diego
B1
Westside
New River
YUHA DESERT
Heber
CALIFORNIA
Los Angeles
Study Area

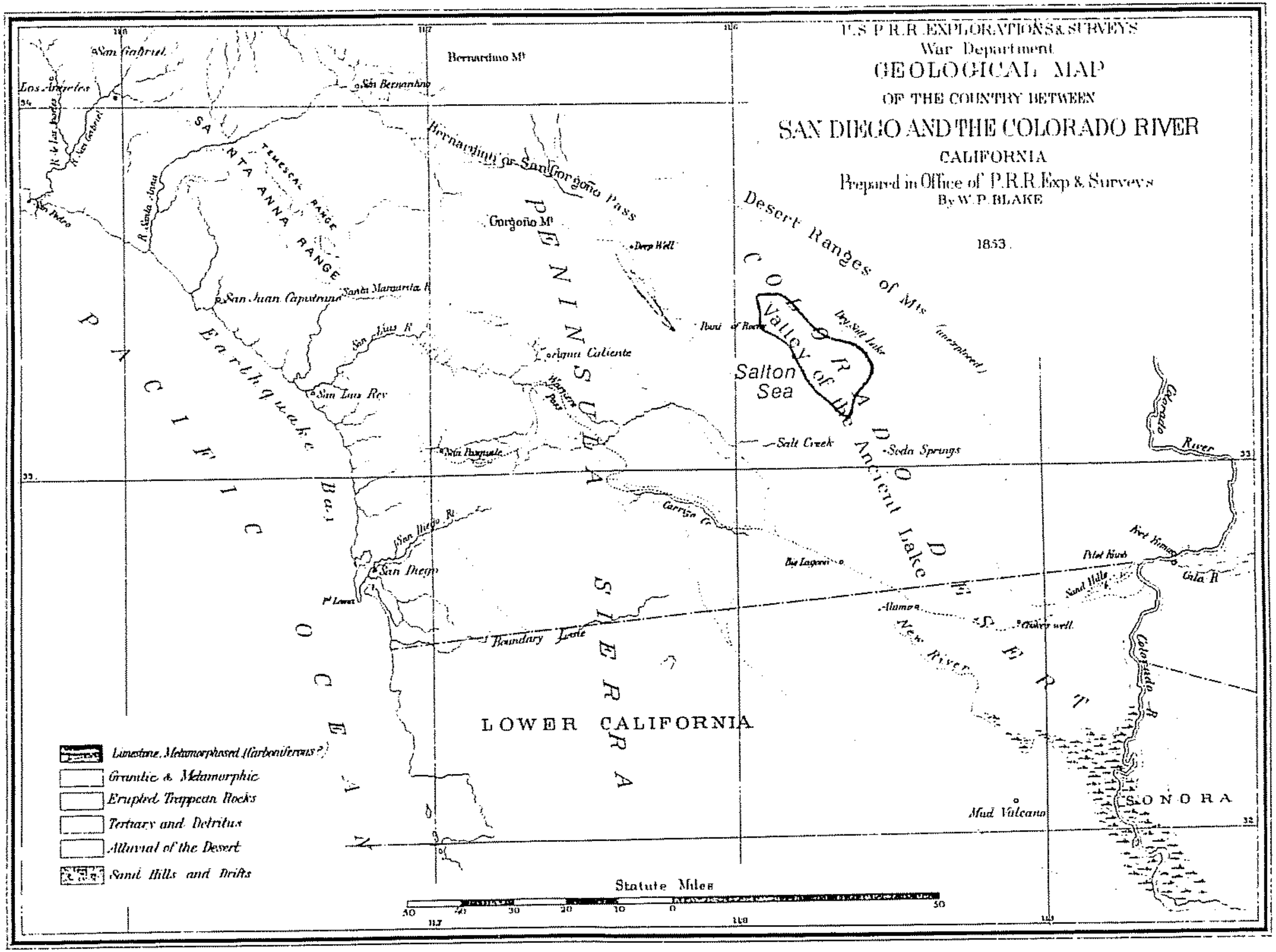


FIGURE 2.--An 1853 map showing southernmost California prior to the formation of the Salton Sea. From Blake (1858). The location of the Salton Sea is superimposed (screened).

DESCRIPTION OF SALTON SEA AREA

Location

The study area occupies the northern part of the Salton Trough and is bordered on the northwest by the San Gorgonio pass, on the west by the San Jacinto and Santa Rosa Mountains and the Peninsular Range of Baja California and southern California, and on the east by the Little San Bernardino and Chocolate Mountains. On the south, the study area is contiguous with the Mexicali Valley in Mexico (fig. 1).

History

In order to identify and understand the potential for agricultural problems in the study area, a brief chronicle of early explorations and key events in the development of agriculture in the Salton Sea area is presented. William Blake, geologist for an expedition in the 1850's to discover possible railroad routes in the southeastern desert area of California, described the Imperial and Coachella Valleys in his "Report of a Geological Reconnaissance in California" (see fig. 2). One of the major features of the valley that attracted Blake's interest is the evidence of a historic lake that had occupied much of the present Coachella and Imperial Valleys (Blake, 1858). Lake Cahuilla was formed by the Colorado River, which flowed into the Salton Trough, depositing its sediments and creating the rich agricultural environment of the Coachella and Imperial Valleys. Early stages of the lake, with a shoreline elevation of 160 feet above sea level, date to 40,000 years B.P. (before the present). More recent shoreline features, at an elevation of about 40 feet above sea level, are dated at 1,500 years B.P. (fig. 3). The historic shoreline is visible at the base of the mountains on the northwest boundary of the Coachella Valley and in the sand dunes on the southeast near the town of Niland.

Buildup of the Colorado River delta blocked the river's flow into the Salton Trough and diverted it to the Gulf of California. As a result, Lake Cahuilla dried up, leaving behind the lacustrine clay and alluvial surface of the Coachella and Imperial Valleys. The disappearance of the lake is documented by dating of the recent shoreline and also by local Indian folklore. In 1853, Blake (1858, p. 248) recognized the agricultural potential of the Imperial Valley and stated, "The whole of this clay surface may be considered as capable of supporting a luxuriant growth of vegetation, provided it is supplied with water by irrigation."

FIGURE 3.--Historic Lake Cahuilla shoreline features. Arrow indicates shoreline (dated at about 1,500 years before the present) at an elevation of about 40 feet above sea level.

In 1901, the California Development Company completed the Imperial Canal to convey Colorado River water to the Imperial Valley, signalling the beginning of agricultural development. Much of this canal was on the Mexican side of the border. On October 11, 1905, a temporary diversion of the Colorado River failed, causing the entire discharge of the river to flow into the Imperial Valley and form the Salton Sea. At the closure of the break in February 1907, the elevation of the Salton Sea was 195 feet below sea level. From 1907 to 1925, the elevation of the sea gradually decreased to its lowest level (since 1905) of 250 feet below sea level as a result of evaporative losses and low volumes of agricultural return (Holbrook, 1928).

In 1922, Imperial Irrigation District (formed in 1911) began installing drainage ditches to convey agricultural effluent away from the fields. In 1924, the Federal Government, by Executive order, withdrew all land below 244 feet below sea level and placed it in a public water reserve. The U.S. Geological Survey investigated future possible stages of the Salton Sea and concluded that, fully developed, the maximum safe elevation of the sea was 220 feet below sea level (Holbrook, 1928). On the basis of information from that investigation, all land below 220 feet below sea level was withdrawn in 1928 and added to the water reserve.

In 1928, passage of the Boulder Canyon Project Act authorized the construction of Hoover Dam, Imperial Dam, and the All-American Canal. Purposes of the projects were to produce hydroelectric power, to reduce silt accumulation in the Colorado River, and to prevent inundation of the Imperial Valley by floods.

Underground tile-drainage systems were installed for the first time in 1929 to relieve salt accumulation in the fields. In 1930, the Salton Sea National Wildlife Refuge was established to preserve wintering habitat for waterfowl and other migratory birds. In 1942, after a decade of construction, Imperial Irrigation District began receiving all of its water from the All-American Canal (fig. 4).

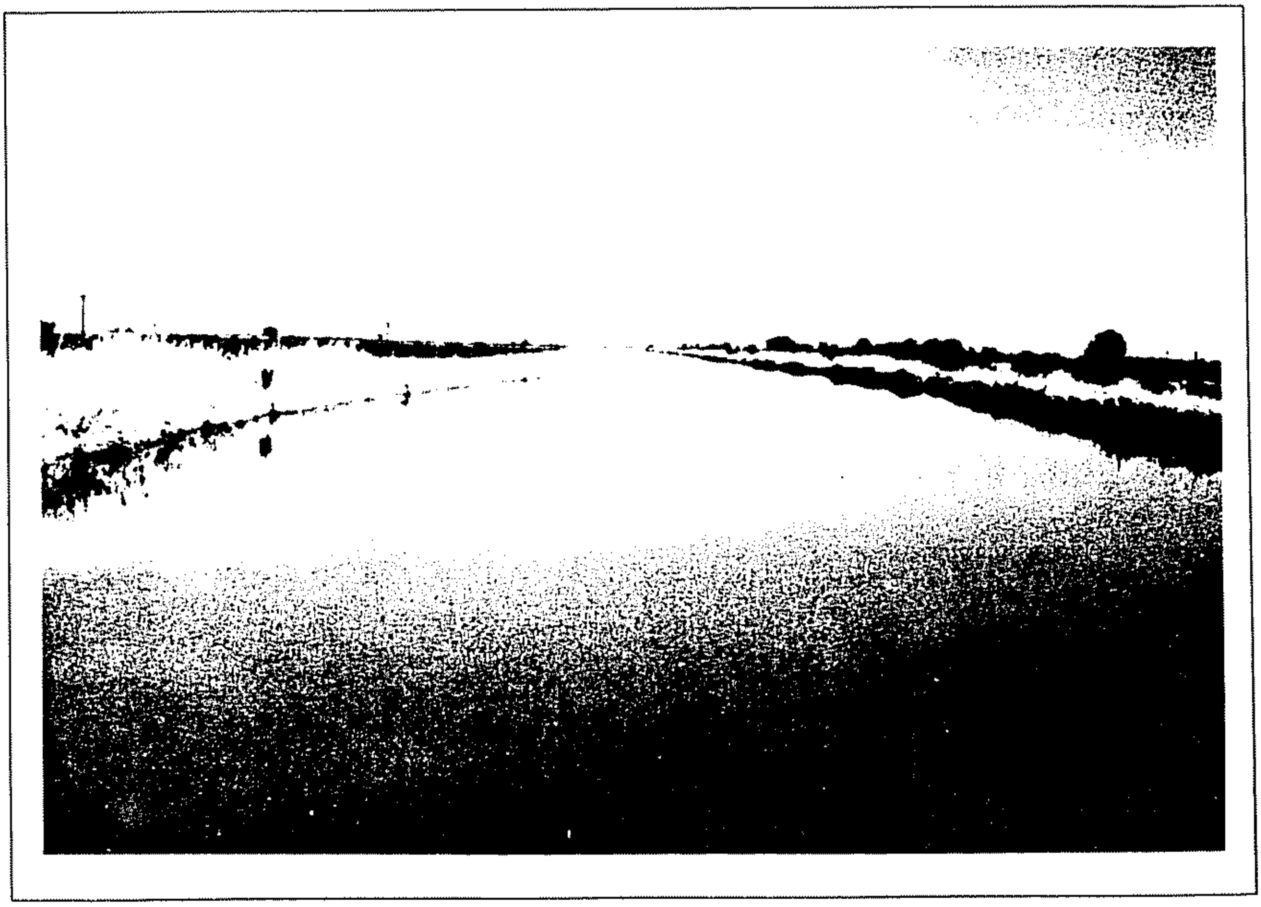


FIGURE 4. -- The All-American Canal (looking east, near Calexico).

Climate

The climate of the Coachella and Imperial Valleys is typical of a desert area and is characterized by hot, dry summers, occasional thunderstorms, and gusty high winds with sandstorms. The Imperial Valley, one of the most arid areas in the United States, has an average annual rainfall of 3 inches. Annual precipitation in the Coachella Valley ranges from 3 inches near Mecca to 9 inches near White Water in the north (fig. 1) (Hely and Peck, 1964). In the Imperial Valley, the maximum temperature is in excess of 100 °F more than 110 days per year. The highest recorded temperature of 119 °F has occurred several times. The average annual temperature on the floor of the Coachella Valley is 73 °F. The average January temperature is 54 °F and the average July temperature is 92 °F (California Department of Water Resources, 1979, p. 4). Evapotranspiration from a growing crop in the Imperial Valley can exceed 6 ft/yr, and in hot summer months can be one-third inch per day (Zimmerman, 1981, p. 4). The frost-free period is greater than 300 days per year for 9 of 10 years and greater then 350 days for 3 of 10 years.

Geology

The geology of Imperial and Coachella Valleys is summarized here in order to describe the geologic influence on irrigation-drainage problems. The geologic summary is based on detailed investigations by Loeltz and others (1975) for the Imperial Valley, and the California Department of Water Resources (1964) for the Coachella Valley.

The Imperial and Coachella Valleys are in a topographic and structural trough, known as the Salton Trough, that extends about 130 miles in length and as much as 70 miles in width. The Salton Trough is a landward extension of the depression filled by the Gulf of California (Loeltz and others, 1975, p. 50), from which it is separated by the broad fan delta of the Colorado River. The surface of the basement complex of early and late Mesozoic plutonic rocks lies thousands to tens of thousands of feet below the basement-complex surface in the bordering mountains. Relief of this magnitude is the result of large-scale downwarping of the Salton Trough, upwarping of the mountains, and faulting and folding of the upper Tertiary and lower Quaternary deposits.

Because the agricultural system in the Imperial Valley is confined primarily to the upper soil horizons (that is, from land surface to a depth of about 10 feet), Quaternary deposits contribute substantially more to naturally occurring water-quality problems associated with agricultural return than do Tertiary deposits. In the central part of the Imperial Valley, within the boundary of historic Lake Cahuilla, the Quaternary deposits are uppermost lacustrine silts, sands, and clays (Loeltz and others, 1975). On the sides of the Imperial Valley, especially on the east, the deposits are well-sorted fine- to medium-grained sands of windblown origin associated with the shoreline of the historic lake.

One geologic feature of current significance in the Imperial Valley is the outcropping of volcanic rocks in a row of small domical buttes along the southeast shore of the Salton Sea (Loeltz and others, 1975, p. 12). These knobs of obsidian, scoria, and pumice, along with carbon monoxide-emitting fumaroles and mud volcanoes, are indicative of geologically recent volcanic activity and high geothermal gradients. To develop this resource, geothermal power plants have been constructed along this high-geothermal-gradient zone.

The Coachella Valley is composed of unconsolidated deposits, partly consolidated deposits, and consolidated rocks. The consolidated rocks, which are exposed in the surrounding mountains, form the basement complex of the valley and define the boundary of the alluvial basin. These consolidated rocks are undifferentiated granitic intrusive and metamorphic rocks of Precambrian and Tertiary ages that contain little or no water (Tyley, 1973, p. 7). The partly consolidated deposits are primarily in the Indio Hills, Mecca Hills, Garnet Hill, and in the area north of Banning. These deposits, of Pliocene and Pleistocene ages, are of low permeability and are poor aquifers (Tyley, 1973, p. 7). The unconsolidated deposits, of late Pleistocene and Holocene age, make up the alluvial basin and constitute the main water-bearing aquifer of the Coachella Valley. The central part of the Coachella Valley historically has been an area of playas and shallow lakes, similar to but commonly larger than the present Salton Sea. Lake Cahuilla, which extended as far north as Indio, deposited the predominant lacustrine silts and clays found from land surface to a depth of 50 to 100 feet. These deposits, distributed in the area that is now the major agricultural center of the Coachella Valley, form a confining layer and are responsible for the partly perched water table located in the lower (southeastern) half of the Coachella Valley.

<u>Soils</u>

The soils of the Imperial Valley are described by Zimmerman (1981). Well-drained to poorly drained soils dominate this lacustrine basin that formerly was occupied by Lake Cahuilla (Zimmerman, 1981, p. 5). According to Zimmerman (1981), "These soils are very deep. They are mainly moderately well drained to well drained, but some soils adjacent to the Salton Sea are poorly drained." The Imperial-Holtville-Glenbar map unit is a major soil of the Imperial Valley and covers about 30 percent of the area. According to Zimmerman (1981),

> *These are very deep calcareous soils formed in alluvial deposits throughout the lake basin. Natural drainage of soils has been altered by the seepage of water from irrigation canals and by extensive irrigation. Slopes are less than 2 percent. Areas of this unit are used mainly for field and vegetable crops. The main management concerns for field or vegetable crops are maintaining a favorable salt balance and keeping the water table below the root zone. These require good irrigation management and the proper use of tile drains.*

A second major soil group consists of well-drained and somewhat excessively drained soils. These soils, found predominantly in the East Mesa and West Mesa areas, cover about 34 percent of the study area. These areas generally are not used for agriculture; they are used primarily for desert recreation or as desert wildlife habitat. The main map unit for this soil group is the Rositas, which constitutes about 20 percent of the study area and is described by Zimmerman (1981, p. 7) as "nearly level to moderately steep, somewhat excessively drained sand, fine sand, and silt loam in alluvial basins and on fans and sandhills."

The surficial soils of the Coachella Valley are more heterogeneous than those of the Imperial Valley. Although much of the basin fill is derived from Colorado River deposits, erosion of the surrounding mountains also contributes material for deposition on the valley floor. Within the boundaries of historic Lake Cahuilla are lacustrine deposits that contain higher clay contents and are generally poorly drained. Soils in this area have contributed to the formation of the partly perched aquifer in the area between Indio and the Salton Sea. It is likely that the two confined aquifers (described in the section "Hydrologic Setting of Salton Sea Area") also were formed from cycles of flooding and deposition of lake sediments.

<u>Land Use</u>

Agriculture is the primary land use in the Imperial Valley; more than 500,000 acres is under irrigation. Field crops are the main agricultural product in the Imperial Valley. Listed in decreasing order of acreage, field crops are cotton, sugar beets, wheat, barley, and sorghum. About 160,000 acres is used for alfalfa, 15,000 for irrigated pasture grasses, and 8,000 for orchards and asparagus (Zimmerman, 1981, p. 29). In addition, about 80,000 acres in 1974 was used for vegetables or melons.

In the Coachella Valley, land use in the Indio area is dominated by citrus and date palms. The Coachella grapefruit is one of the main truck crops and the date groves are some of the finest in the United States. About 80,000 acres of land is under irrigated agriculture in the lower Coachella Valley. A more detailed breakdown of land use to include more specific crop acreages, pesticide usages, and other land-use classifications is beyond the scope of this reconnaissance-level investigation. These more detailed data will be compiled and analyzed during continuing investigations of the study area.

HISTORY OF SALTON SEA NATIONAL WILDLIFE REFUGE

The Salton Sea National Wildlife Refuge was created in 1930 as wintering habitat for migratory waterfowl in the Pacific flyway by Executive Order 5498 signed by President Herbert Hoover. The refuge currently contains more than 45,000 acres and includes large open-water areas, saline wetlands, and uplands. As a result of the continuous rise in the level of the Salton Sea, less than 5,000 acres of saline wetlands, leased cropland, and upland habitat currently exists in the refuge. The rest is open water, which is used by waterfowl for resting and feeding. The refuge provides both nesting and winter habitat for a variety of shorebirds and endangered species. The refuge is especially noted for its variety of birdlife. To date, 372 species of birds have been documented in the area.

More than 90,000 migratory waterfowl currently use the refuge each winter, including approximately 30,000 Canada and snow geese and 60,000 ducks. The predominant duck species at the refuge is the ruddy duck, whose wintering population of 42,000 represents 49 percent of the total number of this species found in the Pacific flyway. Other species of ducks important for waterfowl hunting in the area include mallards, pintails, northern shovelers, green-winged teal, cinnamon teal, wigeon, scaup, canvasbacks, and redheads. Migratory waterfowl usually arrive in November and stay through February.

In addition to migratory waterfowl, many species of colonial nesting birds use the refuge and adjacent wetlands. In 1987, surveys indicated at least 250 great blue herons, 1,600 cattle egrets, and 100 great and snowy egrets nesting in the area. Winter populations of fish-eating birds include 33,000 white pelicans, 2,400 double-crested cormorants, and over 65,000 eared grebes that use primarily the open-water areas of the refuge. Large numbers of black-necked stilts and other shorebirds use the Salton Sea marshlands and unvegetated shallow-water habitats as wintering, nesting, and rearing areas. Endangered species in the area include the Yuma clapper rail, bald eagle, peregrine falcon, and California brown pelican. Other sensitive species occasionally using the refuge include whistling ducks, wood stork, long-billed curlew, mountain plover, and white-faced ibis.

The Salton Sea National Wildlife Refuge, originally created for migratory waterfowl, has evolved into an important recreational asset to the people of the area. Because of the diverse variety of birds, recreational bird watching has, in recent years, become a major use of the refuge area. Some hunting of migratory waterfowl occurs on lands adjacent to the refuge. Camping, fishing, and other outdoor recreational activities also are important.

The rising water level and increasing salinity of the Salton Sea have adversely impacted the fish and wildlife resources over the years. The accelerated inflows from agricultural drainwater during a period of prolonged drought, followed by unusually heavy rainfall for a period of 5 years (1978 to 1983), have resulted in the flooding of almost the entire original acreage of the refuge. Additional purchased or mitigation lands totaling 362 acres have been added since the mid-1970's as the original refuge lands were inundated. Today, 4,716 acres is leased primarily for waterfowl wintering habitat to compensate for the loss of shallow vegetated wetlands to the rising water level.

Important habitat also has been lost to increased salinity and associated changes in vegetation and food resources. The ecological niche has narrowed for some species and widened for others. Although many salt-tolerant species have increased, all biota in the refuge and in the Salton Sea itself have been impacted in recent years by accumulation of contaminants associated with agricultural-irrigation drainwater that empties into the Salton Sea.

Since 1985, the refuge annually has purchased about 2,000 acre-ft of high-quality irrigation water for the active management of 535 acres of wetland and cropland to support wintering migratory waterfowl. Additional efforts to increase the carrying capacity for waterfowl and shorebirds through the purchase of freshwater are currently underway. Since 1979, dikes have been constructed to protect parts of the refuge and reclaim small parcels of formerly inundated wetlands. As the quantity and quality of wetlands elsewhere in California decrease, it becomes increasingly important to protect the remaining wetland habitats at the Salton Sea National Wildlife Refuge from decreasing size and deteriorating quality due to the rising water level and increasing salinity of the Salton Sea.

HYDROLOGIC SETTING OF SALTON SEA AREA

The hydrologic component of most concern for this irrigation-drainage study is the interaction of water and soil in the horizon from land surface to a depth of 6 to 10 feet. Although the alluvium in the Imperial Valley may extend to depths greater than 20,000 feet, the hydrologic connection between the deposits at depths greater than several thousand feet and those in the upper part of the alluvium is so poor that the two parts are virtually isolated (Loeltz and others, 1975, p. 14). Irrigation practices and ground-water recharge from canal leakage are determined by the physical and chemical characteristics of the upper alluvium. Currently, irrigation tailwater and leakage of water from the unlined All-American Canal and from Imperial Irrigation District distribution canals are the major sources of recharge to the shallow ground-water reservoir. Much of this recharge does not reach the water table, but is discharged by an extensive network of underground tile drains and drainage ditches to the New and Alamo Rivers (Loeltz and others, 1975, p. 19).

Irrigation Water

A schematic of the movement of irrigation water in the Salton Sea area is shown in figure 5. Irrigation water for the Imperial Valley and much of the Coachella Valley is supplied by the U.S. Bureau of Reclamation from diversion of Colorado River water at the Imperial Dam to the the All-American Canal. The All-American Canal is an 80-mile-long unlined conveyance delivering about 3 million acre-ft of water per year. The Coachella Canal, which originates from the All-American Canal west of the Sand Hills and the Yuma Proving Grounds, is a 123-mile-long canal conveying irrigation water to about 80,000 acres of agricultural land in the lower Coachella Valley north of the Salton Sea.

Irrigation water within the Imperial Valley is distributed by the Imperial Irrigation District through a network of about 1,600 miles of canals and laterals. Most of the major canals, such as the East Highline, Central Main, and Westside Main, are unlined. Leakage from these canals is a major source of recharge to the partly perched aquifer. Many of the laterals originating from these and other major canals are concrete lined. Water requested by the growers is diverted from these laterals and applied to the fields for irrigation and to leach accumulated salts from the soils. Excess water from leaching, along with lateral flow from leakage of the unlined canals, is intercepted by tile drains. Average depth of the drains is about 6 feet below land surface, and horizontal spacing is dependent on soil characteristics. Spacing ranges from 50 feet in silty clay soils to 400 feet in sandy soils. The water from the tile drains is discharged to a network of about 1,400 miles of surface-drainage ditches or collector drains. These collector drains, which also intercept underground flow from the fields and convey tailwater runoff, discharge into the New or Alamo Rivers. A few of the drains near the Salton Sea discharge directly to the Salton Sea. The New and Alamo Rivers discharge to the southern end of the Salton Sea near the Salton Sea National Wildlife Refuge. The refuge is located in the delta area of the two rivers and is a major waterfowl habitat in the Salton Sea area.

Surface Water

The combined flow of the New and Alamo Rivers from the south is the main source of water replenishment for the Salton Sea. The discharge of the Alamo River at the outlet to the Salton Sea is about 600,200 acre-ft/yr; however, only 1,842 acre-ft/yr enters the United States at the international boundary (Fogleman and others, 1986). (All discharges given here are for the 1984 water year unless otherwise noted.) Most of the discharge (of 600,200 acre-ft) at the outlet is agricultural effluent from the Imperial Valley. The New River at the outlet to the Salton Sea has an annual discharge of 512,000 acre-ft. Water in the New River at the international boundary is a major source of potential contaminants. The annual discharge of 262,640 acre-ft at the international boundary is composed of municipal effluent from Mexicali (population in excess of 750,000), along with industrial and agricultural effluent from the Mexicali Valley. Water quality in the New River at the international boundary was determined in order to isolate the influence of contaminants contributed by the industry and populace of Mexicali from that of contaminants contributed by irrigated agriculture in the Imperial Valley. Other sources of surface discharge to the Salton Sea include ungaged drains, which during 1944-62 contributed an average annual flow of about 131,000 acre-ft (Hely and others, 1966, p. C7).

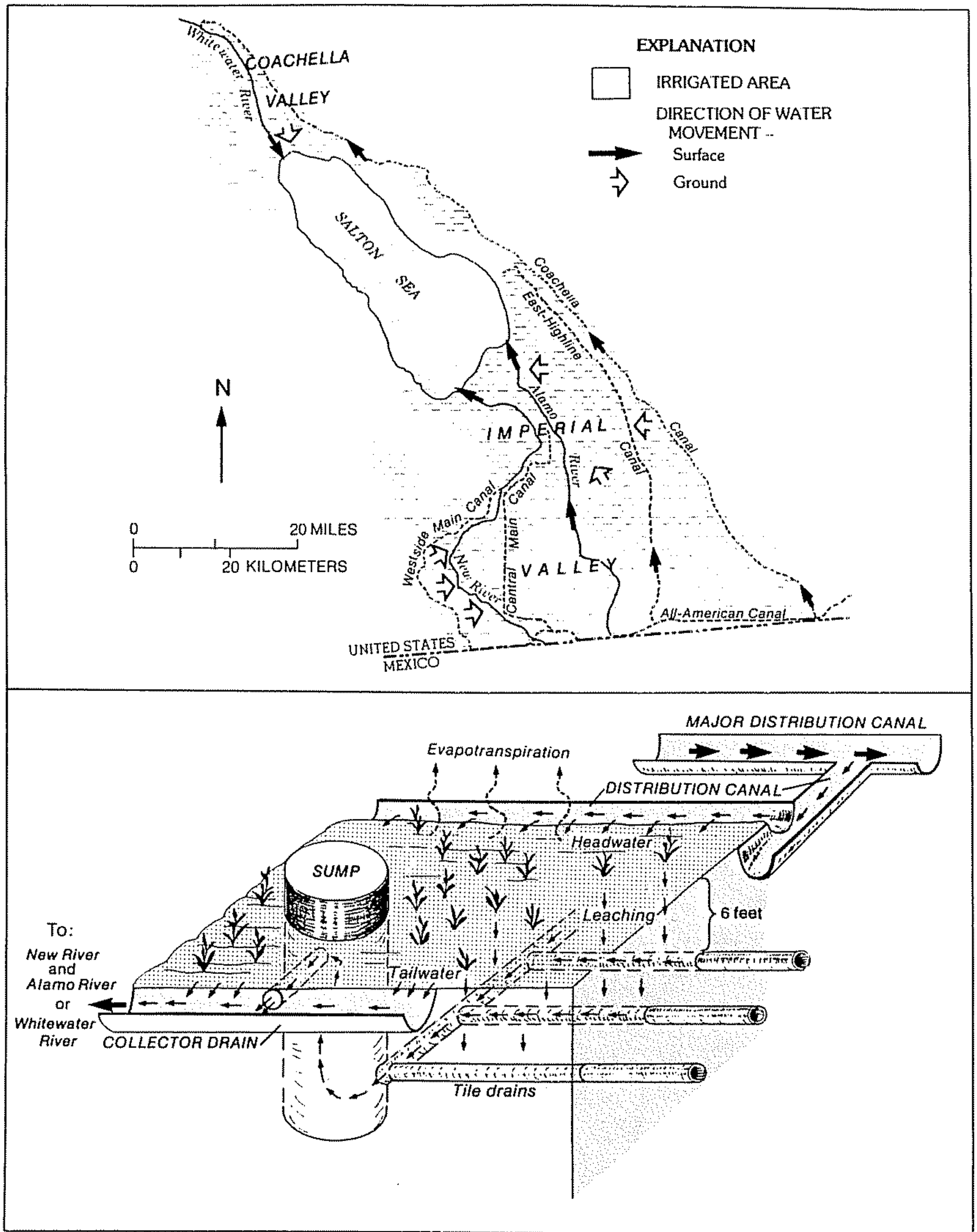


FIGURE 5.--Generalized schematic of water movement in the irrigated areas of the Coachella and Imperial Valleys.

By comparison, water replenishment to the Salton Sea from the Whitewater River, which flows through the Coachella Valley, is only 80,000 acre-ft/yr; or about 6 percent of the surface-water inflow to the Salton Sea. Ungaged drains contribute less than one-half this amount. The other source of surface water to the Salton Sea is San Felipe Creek, which flows eastward from Lower Borrego Valley and has an average annual discharge of 5,600 acre-ft. Within the San Felipe Creek drainage, near the Salton Sea, a new agricultural area has been developed. Water quality from this newly developed area might be indicative of drainage-water quality in other parts of the Imperial Valley when irrigated agriculture began.

In 1987, the surface elevation of the Salton Sea was 226 feet below sea level. Annual fluctuations in the elevation of the Salton Sea from 1904 to 1962 (and surface inflow and evaporation for 1908-60) are shown in figure 6, and contours of the Salton Sea bed are shown in figure 7. Although the elevation of the Salton Sea has risen about 8 feet since 1962 to its present level, current irrigation practices of water conservation probably will stabilize its future surface level. Because the Salton Sea is in an arid environment, evaporation is an important component of the hydrologic regimen of the Salton Sea. The average annual evaporation from the Salton Sea for the period 1948-62 was 5.78 feet (Hely and others, 1966, p. C18). This evaporation, and the lack of any outflow, has led to an increase in the salinity from 3,550 mg/L in 1907 when the Salton Sea was formed (Hely and others 1966, p. C22) to 41,000 mg/L in 1986 (California Regional Water Quality Control Board, written commun., 1986). This is more than a tenfold increase in salinity. Current salinity exceeds that of seawater (35,000 mg/L).

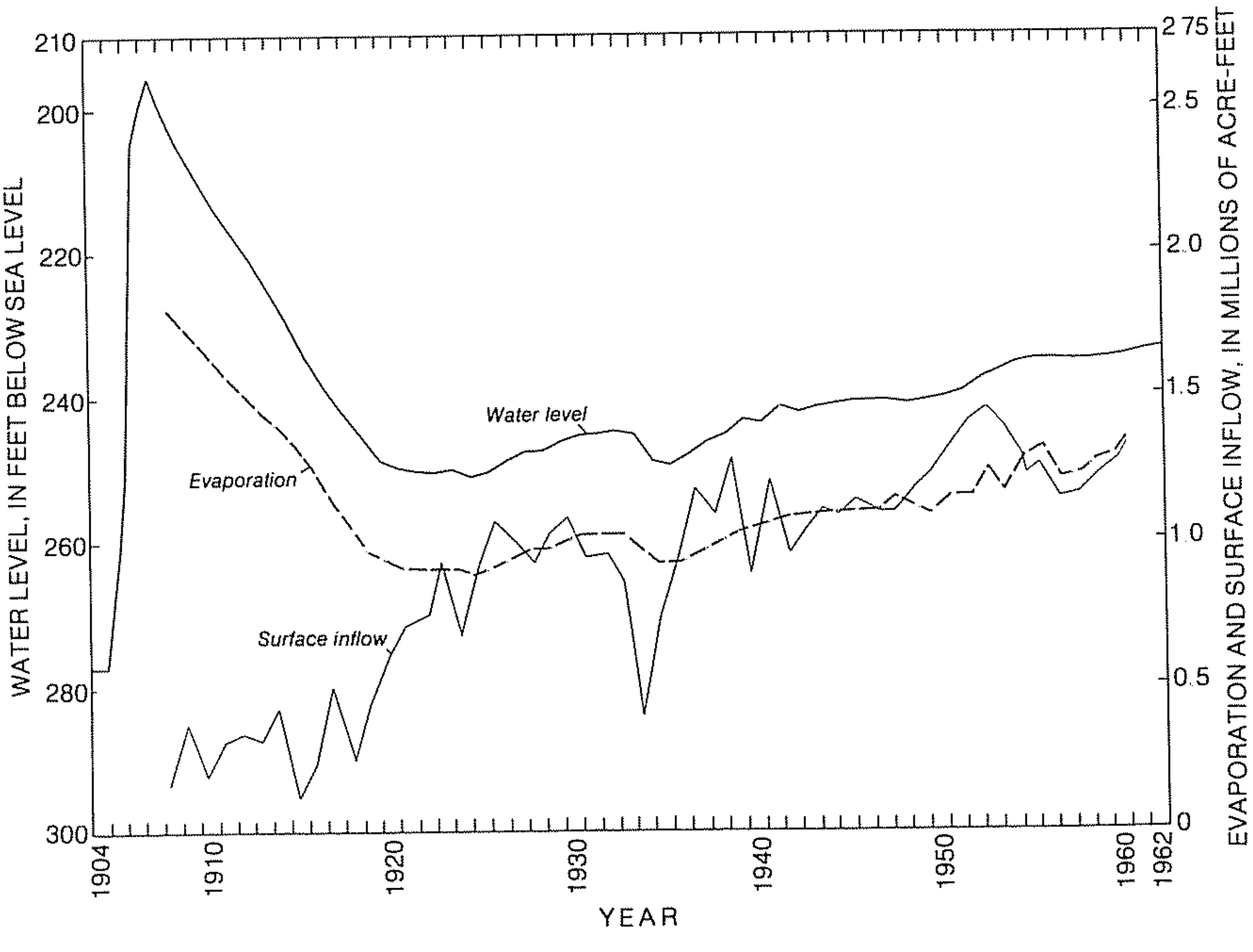


FIGURE 6.-- Water level (1904-62) and surface inflow and evaporation (1908-60) at the Salton Sea. (From Hely and others, 1966.)

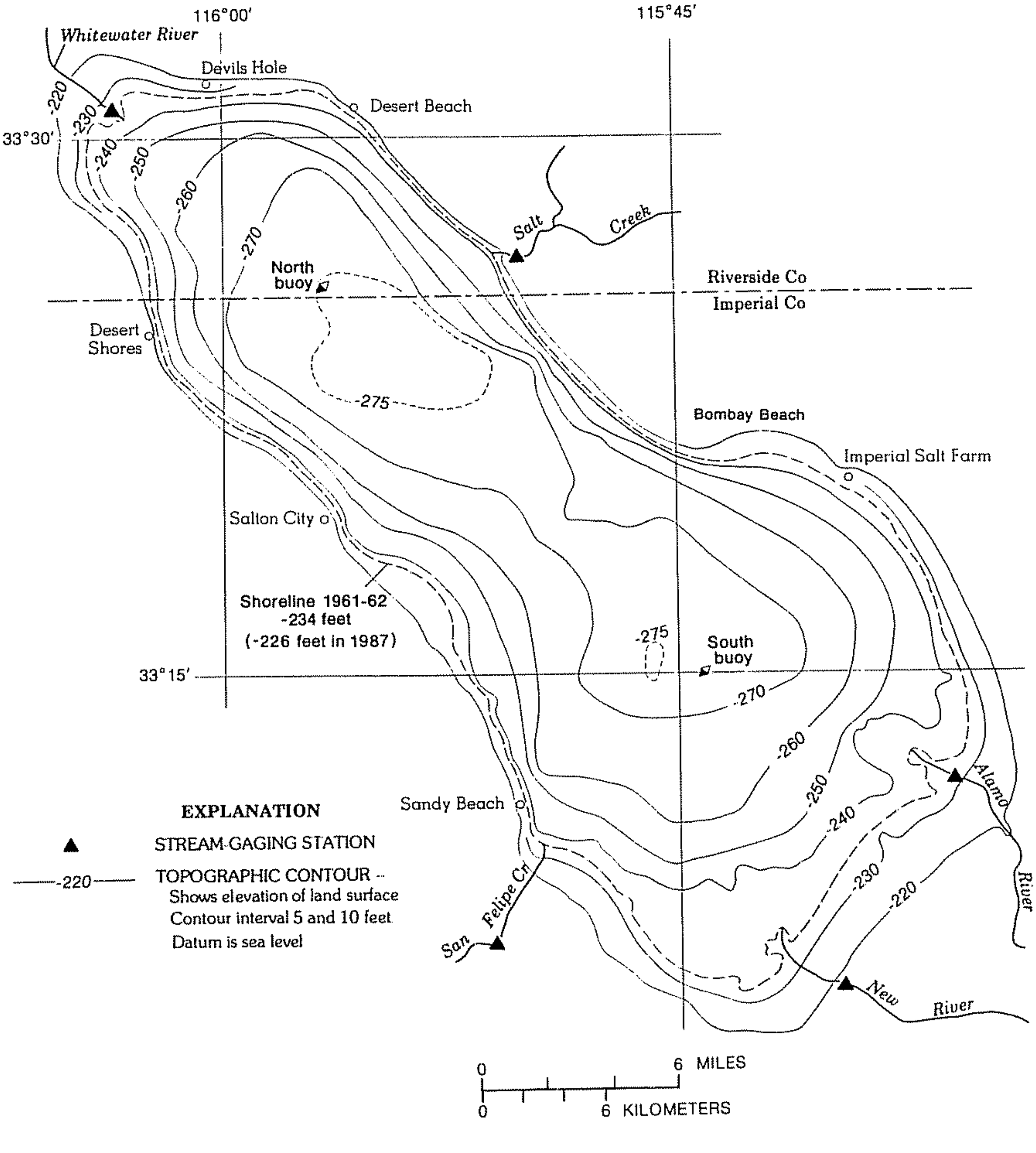


FIGURE 7. -- Contours of the Salton Sea bed. (From Littlefield, 1966, as modified by Hely and others, 1966.)

Ground Water

In comparison with surface inflow, ground-water recharge to the Salton Sea is a small component of the total inflow. Ground-water flow to the Salton Sea from the Imperial Valley is about 2,000 acre-ft/yr, and alluvium bordering San Felipe Creek contributes about 10,000 acre-ft/yr (Hely and others, 1966, p. C9). Most of the ground water from the Imperial Valley is intercepted by the network of tile drains and drainage ditches that discharge as surface water to the Salton Sea. The general direction of ground-water movement is from the unlined canals (such as the Coachella Canal) toward the Alamo River and then northwestward toward the Salton Sea (Loeltz and others, 1975, p. K23). A perched water table is present in much of the Imperial Valley as a result of the surface application of irrigation water and the low permeability of much of the soils (Zimmerman, 1981, p. 5).

The main growing area within the lower Coachella Valley extends from Indio to the Salton Sea. This area contains upper and lower confined aquifers, as well as a partly perched aquifer. (The partly perched condition is maintained by irrigation return of Colorado River water, which is supplied by the Coachella Canal and which is the main source of artificial recharge to the lower Coachella Valley.) Depth to water in the partly perched aquifer ranges from about 5 to 30 feet below land surface. The difference between the potentiometric heads in the partly perched aquifer and those in the confined aquifers indicates an upward component of flow from depth into the partly perched aquifer. Ground-water discharge through the upper and lower aquifers southeastward to the Salton Sea is estimated to be 30,000 acre-ft/yr (California Department of Water Resources, 1980, p. 17). Water from the partly perched area discharges as surface outflow in drainages to the Salton Sea; in drainages to the Whitewater River, which discharges to the Salton Sea; and by evaporation.

PREVIOUS STUDIES

Water and Bottom Sediments

Eccles (1979) studied the areal and temporal distribution of selected pesticides in agricultural drains of California's southeastern desert. Water and bottom-sediment samples were collected from selected tile drains, collector drains, and rivers for analysis of pesticide concentrations. The suite of pesticides analyzed was determined by current and prior usage. Pesticide classes analyzed included organochlorine and organophosphorus insecticides, and triazine and chlorophenoxyacid herbicides. Pesticide distribution was determined both areally and temporally. Results of the water-sample analyses from 20 sites indicated that the tile drainage had practically no detectable pesticide concentrations. These results are similar to those from a July 1985 sampling of the San Luis Drain area in the western San Joaquin Valley in which samples from only 2 of 14 drains (14 percent) had detectable pesticide concentrations. In contrast, samples from 10 of 25 wells (40 percent) in the San Luis Drain area had triazine herbicide residues (J.G. Setmire, U.S. Geological Survey, written commun., 1985). In 1977, Eccles (1979) sampled 17 collector drains in the southeastern desert for a total of 119 analyses. Residues of 10 pesticides were detected in more than 20 percent of the samples (table 1).

Bottom-sediment samples from the 1977 sampling had elevated pesticide concentrations of compounds no longer in use in the study area. Most detections were for the DDT [1,1,1-trichloro-2,2-bis(p-chlorophenyl)-ethane] metabolites, DDD [1,1-dichloro-2,2-bis(p-chlorophenyl)ethane], and DDE [1,1-dichloro-2,2-bis-(p-chlorophenyl)ethylene]. Even though DDT use was banned by the U.S. Environmental Protection Agency in 1972, residues still were being detected in this 1977 sampling. DDE is the main metabolite in the breakdown of DDT. DDD is another metabolite (also a metabolite of the formerly manufactured pesticide TDE or Rothane). Concentrations of these pesticide residues from the 1977 sampling are presented along with the results from the reconnaissance sampling.

Table 1.--*Concentrations of selected pesticides in 119 water samples collected from 17 collector drains in the southeastern desert of California, 1977*

[Data from Eccles, 1979, table 3. All concentrations in micrograms per liter]

Pesticide	Number of detections	Median concentration	Maximum detected concentration
DDE	72	0.02	1.3
DDT	37	.02	.33
Diazinon	66	.09	8.3
Dieldrin	66	.01	.05
Endosulfan	53	.03	1.7
Ethyl parathion	50	.04	8.1
Methyl parathion	57	.06	120
Silvex	70	.08	6.8
Simazine	28	1.4	4.4
2,4-D	71	.07	2.9
Other pesticides that were detected in less than 20 percent of the samples but at significant maximum concentrations:			
Azodrin	11	0.06	25
DDD	23	.02	.26
Malathion	22	.07	8.5
Phosdrin	19	.05	5.4
Prometon	17	.7	6.6

Eccles (1979, p. 55) concluded that there were practically no detectable pesticide concentrations in tile-drainage effluents and generally slight concentrations of presently used pesticides in the bottom sediment in the drains. He concluded, also, that the highest pesticide concentrations were derived from aerial drift and from irrigation tailwater.

Irwin (1971) studied pesticides and inorganic nitrogen and phosphorus concentrations in water from the New and Alamo Rivers. Sampling locations included one on the East Highline Canal, three on the New River, four on the Alamo River, and a background site on the All-American Canal. Samples were collected monthly for 1 year during 1969-70. Analyses were done for about a dozen commonly used pesticides. Concentrations in both rivers generally were somewhat higher than Eccles later found in Imperial Valley drainage ditches. Concentrations of pesticides, and of nitrate and orthophosphate, increased from south to north, reflecting increasing input of agricultural return flow. The only exception to this pattern is DDT and its metabolites in the New River. Concentrations of those pesticides generally were highest near the international boundary.

Setmire (1979, 1984) conducted studies on the New River in 1977-78 that focused primarily on oxygen and oxygen demand. He attributed low oxygen in the river to discharge of sewage from Mexicali, Mexico. Periodic slugs of what appeared to be an industrial material also were observed. Heavy-metal concentrations nearly always were below drinking-water and freshwater-aquatic criteria established by the U.S. Environmental Protection Agency (1976). Few samples were collected, however, and detection limits were much higher than for samples analyzed during this reconnaissance study.

Data obtained at National Stream Quality Accounting Network stations in the Imperial Valley indicate that arsenic and selenium concentrations may be high. Arsenic concentration occasionally exceeded the U.S. Environmental Protection Agency (1986a) drinking-water standard (50 $\mu g/L$) in the New River, and the median selenium concentration in the Alamo River is equal to the U.S. Environmental Protection Agency (1986a) drinking-water standard (10 $\mu g/L$).

In 1985, the California Regional Water Quality Control Board, Colorado River Basin Region (Regional Board) collected samples from a variety of sources and locations in the Imperial Valley for selenium analysis by the California Department of Water Resources. The data are presented, along with results of the Department of the Interior reconnaissance, in the section "Areal Variation of Constituents in Water." Tile drains clearly are identified to be the main source of selenium. Elevated concentrations of selenium also were detected in San Felipe Creek (29 $\mu g/L$) (P.A. Gruenberg, California Regional Water Quality Control Board, written commun., 1987). This stream was not sampled during the reconnaissance because it does not pass through the refuge boundaries, nor are the lands irrigated with All-American Canal water.

In June 1986, the Regional Board sampled water from 119 tile drains and 36 other collector drains and river sites in the Salton Sea area. These water samples were analyzed for trace-element concentrations, with an emphasis on selenium. Results from this intensive sampling also are presented in the section "Areal Variation of Constituents in Water." Data from the 1986 sampling corroborate the previous year's sampling. Selenium concentrations were highest in the tile drains, generally less than 10 $\mu g/L$ in collector drains, and less than 2 $\mu g/L$ in the Colorado River and Salton Sea.

Biota

Researchers at the Lawrence Livermore Laboratory found high selenium concentrations in livers from wintering waterfowl in the Imperial Valley (Koranda and others, 1979). Mean concentrations (dry weight) were 15 $\mu g/g$ in green-winged teal, 15.6 $\mu g/g$ in shovelers, 11.2 $\mu g/g$ in pintails, and 49.5 $\mu g/g$ in ruddy ducks.

The California Department of Fish and Game detected selenium levels of concern in several species of Salton Sea fish collected in 1986 (White and others, 1987). Of the three fish species (corvina, tilapia, croaker) sampled, tilapia had the highest average selenium concentration in liver tissues, 6.8 $\mu g/g$ (wet weight). An arithmetic mean was used to report these levels. Mean muscle-tissue concentrations, in micrograms per gram (wet weight), were fairly consistent for the fish species collected: 3.1 for corvina, 3.5 for tilapia, and 3.9 for croaker.

Water birds collected by the California Department of Fish and Game (White and others, 1987) showed a greater variation in selenium concentration than did fish. Only four bird species were sampled: lesser scaup, double-crested cormorant, black-necked stilt, and wigeon. Selenium concentration in liver tissues (in micrograms per gram, wet-weight) were: wigeon, 1.3; lesser scaup, 3.1; black-necked stilts, 5.2; and double-crested cormorant, 9.7. In muscle tissues, the concentrations were: wigeon, 0.98, and lesser scaup, 1.2 $\mu g/g$. The highest single selenium concentration was 18 $\mu g/g$ in the liver of a double-crested cormorant.

Organochlorine pesticide residues have been reported for fish and birds collected in the Salton Sea basin. Concentrations of DDE, a metabolite of DDT, were higher in waterfowl collected from the Salton Sea than from similar samples from Mexico (Mora, 1984). High DDE concentrations were observed in water-bird eggs collected in 1985 from the Salton Sea basin (H.M. Ohlendorf, U.S. Fish and Wildlife Service, oral commun., 1988). Fish collected in 1985 and analyzed for pesticides contained elevated levels of DDT and its metabolites (M.K. Saiki, U.S. Fish and Wildlife Service, oral commun., 1988). (As used here, the term "elevated levels" denotes concentrations greater than geometric mean concentrations [DDT, 0.05 $\mu g/g$; DDE, 0.20 $\mu g/g$; DDD, 0.07 $\mu g/g$ wet weight] from the National Contaminant Biomonitoring Program.) Fish samples collected by the State of California from various locations in the Salton Sea and its associated rivers and drains also contained elevated tissue levels of DDT metabolites (Linn, 1987). The U.S. Environmental Protection Agency in 1985 (written commun., 1985) did organochlorine scans on samples of four species of fish: corvina, sargo, tilapia, and gulf croaker. Results showed elevated levels of DDT and its metabolites, organic solvents, and pesticide residues.

SAMPLE COLLECTION AND ANALYSIS

Selection of Sampling Sites

Selection of sampling sites was dependent on several factors, including funding constraints, availability of previous data, and representativeness. The main criteria for selection were that the sites be representative of irrigation return within the study area and, in addition, provide some temporal continuity with samples collected in previous U.S. Geological Survey investigations. A description of sampling sites and constituents analyzed for at each site is given in table 2, and sites are shown in figure 1. Bottom-material samples were collected at 15 sites, including a composite site in the Salton Sea. To facilitate sample collection, a sampling site on the All-American Canal was changed to site 1 on the East Highline Canal, a major diversion of the All-American Canal. Water from this site is representative of the irrigation water supplied to the Imperial and Coachella Valleys and is designated the control site. A control site in this context shows the quality of irrigation water to be applied to fields within the study area. Although water data were not collected during the reconnaissance investigation, water-quality data were supplied by the California Regional Water Quality Control Board. Eight tile drains were selected on the basis of spatial representativeness of the general area to be sampled and on the availability of water and ease of sampling during the field reconnaissance.

The five biological sampling sites (B1-B5) were located to correlate as much as possible with the water and bottom-sediment sites (fig. 1). One of two "control" sites was established on the New River in Imperial County at an area called Rio Bend about 40 air miles south of Salton Sea National Wildlife Refuge. The New River at Rio Bend site (B1, fig. 8), at River Mile 11, is 6.5 air miles north of the international border. The other "control" site (B2, fig. 9) was located at the Whitewater River delta in Riverside County, 36 air miles northwest of the Salton Sea National Wildlife Refuge (fig. 9). These sites are considered control sites only because irrigation drainwater from agricultural areas in the United States does not make up a major portion of the water impacting the sites. The New River at Rio Bend site (B1) is impacted by municipal and industrial effluent from Mexico as well as some irrigation drainwater from Mexican agricultural areas. The Whitewater River contains municipal and some industrial effluent and minimal agricultural drainwater. There were no true control areas (that is, free of contaminants) in the Salton Sea basin that had sufficient biological specimens for collection

Samples of biota were collected at three other sites that were in or near the Salton Sea National Wildlife Refuge and known to be affected by irrigation drainwater from agricultural fields. These three agricultural-drainwater sites (figs. 1 and 10) were: Trifolium/Vail Drains (B3), New River delta (B4), and the Alamo River delta (B5) (fig. 1 only).

Sampling Methods

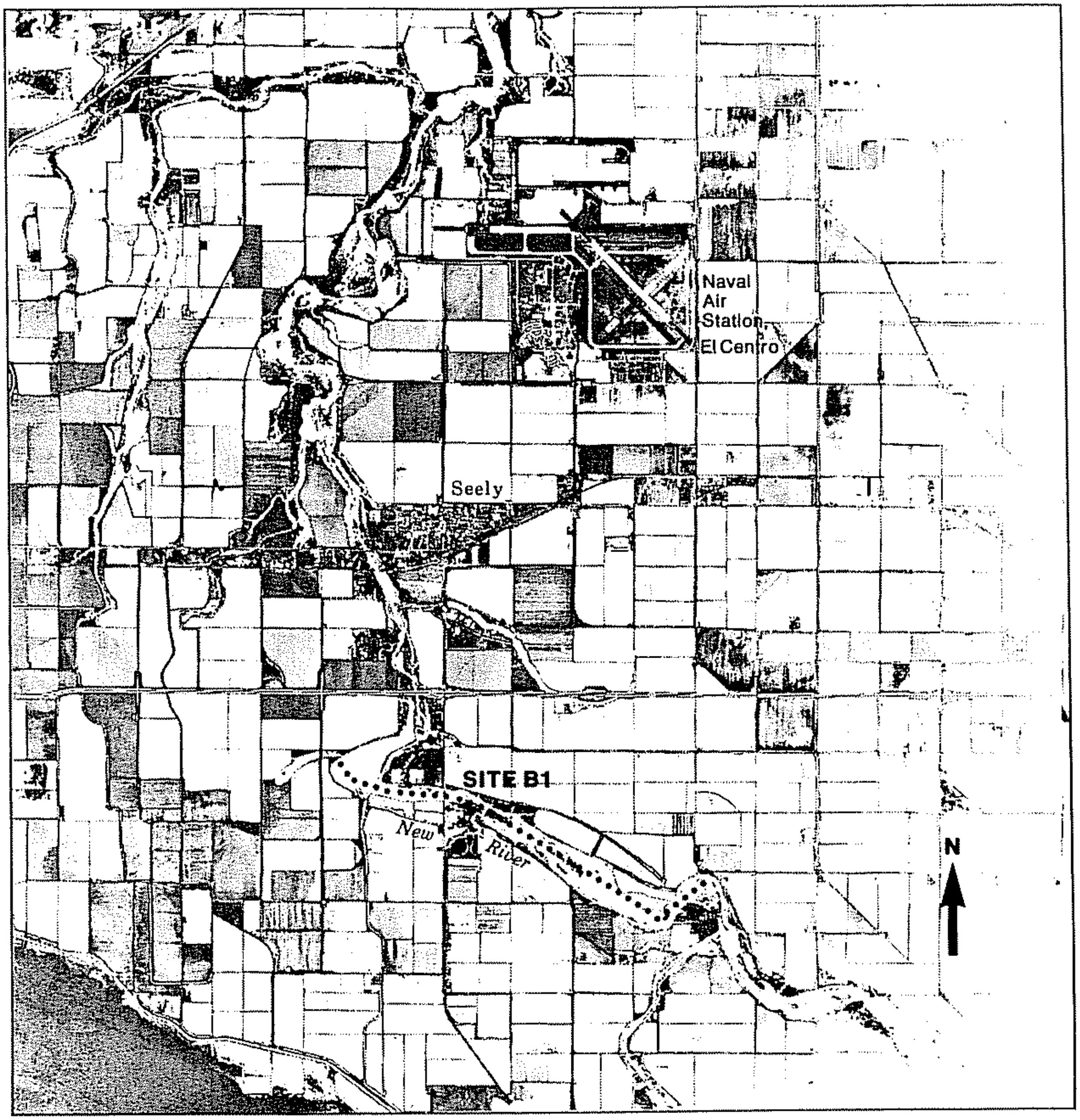
Water and Bottom Sediments

Methods for sample collection and processing were specified in the protocol established by the Department of the Interior Irrigation Drainage Task Group. Some modifications were necessary depending on field conditions encountered at each site. The New and Alamo Rivers are too deep at most sites to wade across the channel, and, where bridges are present, riprap or other erosion-protection structures and debris prevented the use of the U.S. Geological Survey's BMH-60 spring-activated bottom-sediment sampler. At these sites, samples were collected along transects near the bank, where silt deposition was greatest and water was shallow enough to wade, using the BMH-53 hand-operated piston-type corer. The Alamo River at the international boundary (site 2) was wadable because flow was less than 1 ft^3/s. The collector drains (sites 8-11) and the Whitewater River at the downstream site (site 13) also were wadable and those sites were sampled with the BMH-53 corer. Individual cores collected along transects were composited into stainless-steel buckets and sieved in the field through a 62-micrometer (pore size) sieve. Depth-integrated samples for water-quality analysis of the New and Alamo Rivers were collected along a transect from the bank toward midstream, depth permitting. The field drains were sampled either from the sump or directly from the pipe exiting the field. The upstream site on the Whitewater River (site 12) was dry. Bottom material was collected with a small hand-scoop from six locations traversing the channel. Site 1, the East Highline Canal, was sampled using the BMH-60 sampler. Multiple water and bottom-sediment samples from an offshore transect of the Salton Sea (site 15) were collected from a small boat and composited for analysis. Unsieved samples also were sent for analysis (see p. 26).

Table 2.--*Sampling sites and sample matrix for the Salton Sea reconnaissance investigation*

[Matrix: BS, bottom sediment; W, water; B, biota. Constituents: MI, major ions; OC, organochlorine pesticides; OP, organophosphorus pesticides; RN, radionuclides; TE, trace elements; VO, volatile or purgeable organics. Location of sites shown in figure 1]

Site No.	Description	Matrix/ constituents
	Bottom-sediment and (or) water sites	
1	East Highline Canal diversion from All-American Canal (control site).	BS/OC+TE
2	Alamo River at international boundary.	BS/OC+TE
3	New River at international boundary.	BS/OC+TE
4	Alamo River at Imperial Wildlife Management Area.	BS/OC+TE
5	New River at midpoint of U.S. reach.	BS/OC+TE
6	Alamo River at outlet to Salton Sea.	BS/OC+OP+TE, W/OP+TE+MI
7	New River at outlet to Salton Sea.	BS/OC+OP+TE, W/OP+TE+MI
8	Trifolium Drain 1 (collector drain).	BS/OC+TE, W/OP+TE+MI
9	Trifolium Drain 4 (collector drain).	BS/OC+TE
10	Vail Drain 4 (collector drain).	BS/OC+TE
11	T-drain at Imperial Wildlife Management Area (collector drain).	BS/OC+TE
12	Whitewater River upstream from Highway 111.	BS/OC+TE
13	Whitewater River at outlet to Salton Sea.	BS/OC+TE
14	Avenue 64 Evacuation Channel at Highway 195.	BS/OC+TE
15	Salton Sea composite of four samples near biological site B5. Sampled by boat.	BS/OC+OP+TE, W/TE+OP+MI
Tile drains 1-8	Sampled from outflow pipe or sump.	W/TE+VO +RN+MI
	Biological sites	
B1	New River at Rio Bend, near Interstate 8 (control site).	B/TE+OC
B2	Whitewater River delta (control site).	B/TE+OC
B3	Trifolium/Vail Drains.	B/TE+OC
B4	New River delta.	B/TE+OC
B5	Alamo River delta.	B/TE+OC



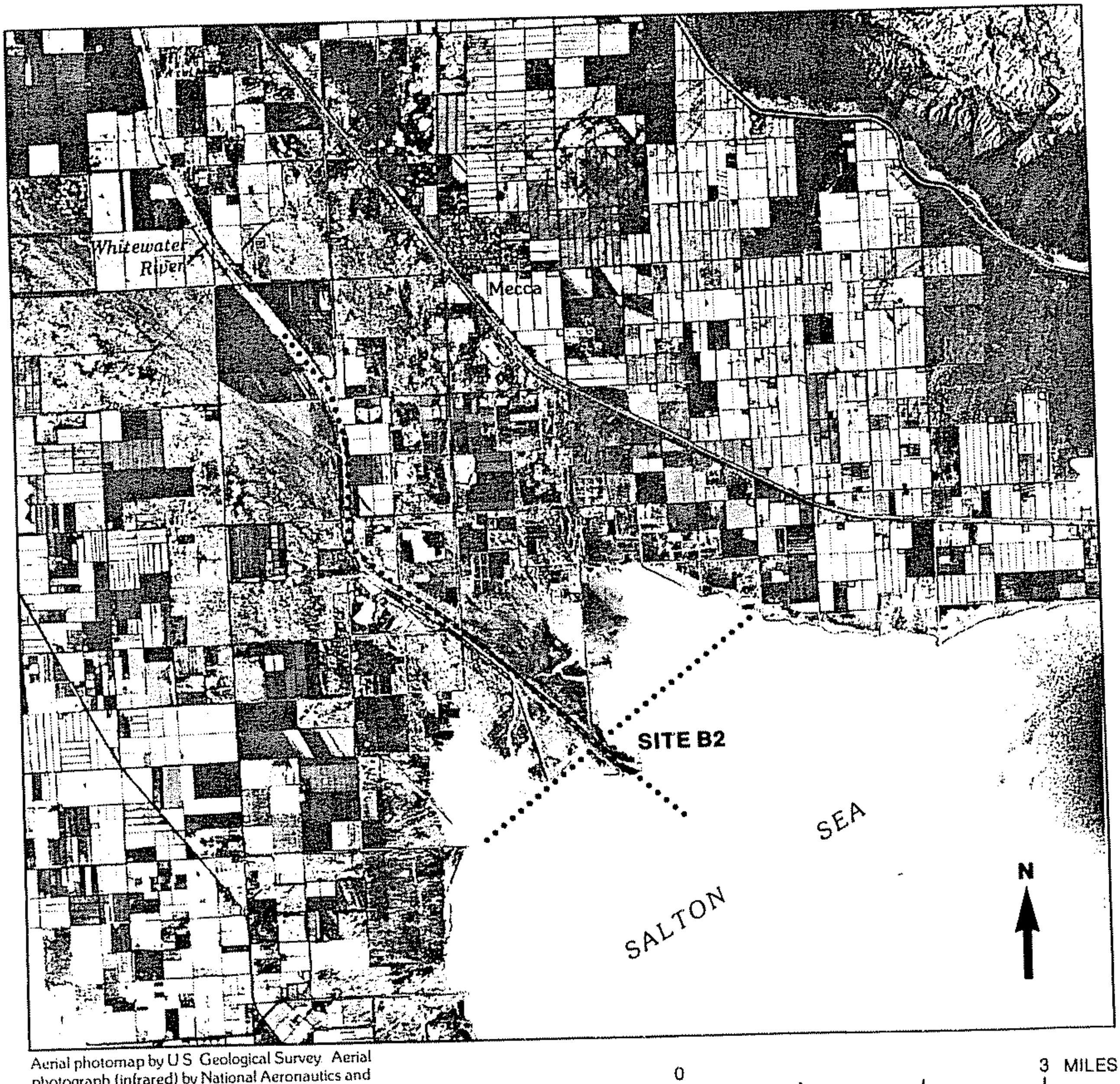
Aerial photomap by U S Geological Survey Aerial photograph (infrared) by National Aeronautics and Space Administration (National High Altitude Aerial Program). August 1984

0 3 MILES
0 3 KILOMETERS

EXPLANATION

•••••••• LOCATION OF SAMPLING TRANSECT

FIGURE 8.-- New River at Rio Bend biological sampling site (B1) south of the Salton Sea. See figure 1 for location of photomap area.

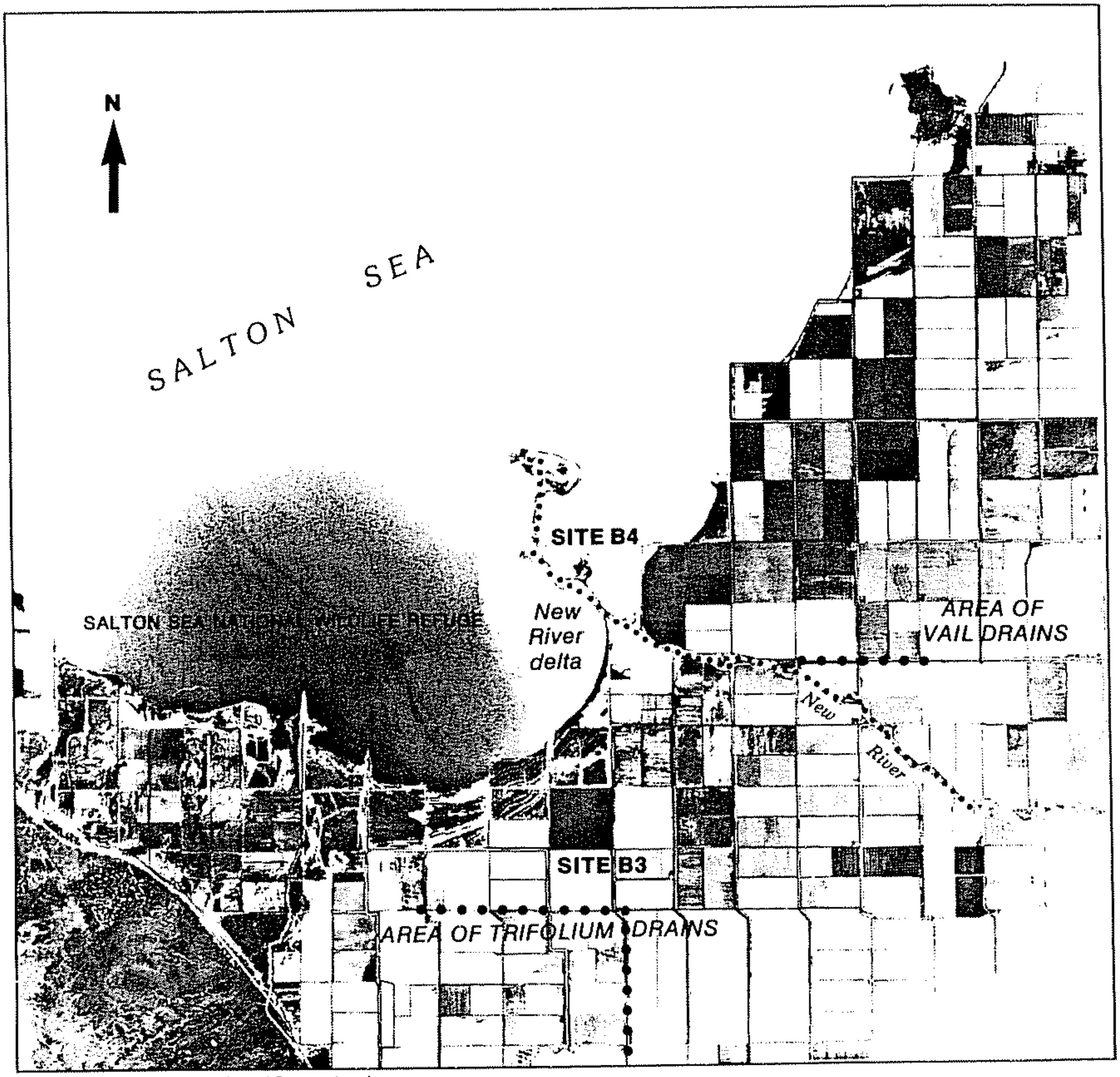


Aerial photomap by U S Geological Survey. Aerial photograph (infrared) by National Aeronautics and Space Administration (National High Altitude Aerial Program) August 1984

EXPLANATION

•••••• LOCATION OF SAMPLING TRANSECT

FIGURE 9.--Whitewater River delta biological sampling site (B2). See figure 1 for location of photomap area.



Aerial photomap by U.S Geological Survey Aerial photograph (infrared) by National Aeronautics and Space Administration (National High Altitude Aerial Program) August 1984

0 3 MILES
0 3 KILOMETERS

EXPLANATION

LOCATION OF SAMPLING TRANSECT--

● ● ● ● ● Site B3

• • • • • • • • Site B4

FIGURE 10.--Trifolium/Vail Drains (B3) and New River delta (B4) biological sampling sites. See figure 1 for location of photomap area.

Biota

Samples of biota, including plants, invertebrates, fish, and water birds, were collected to demonstrate the accumulation of contaminants within a food chain or at various trophic levels. Table 3 lists the species and sample types collected during the reconnaissance study. The occurrence of a particular species at any given site was highly variable because each site presented a different habitat.

Most biological samples submitted for analysis were composite samples of three or more individual specimens. Samples were collected, prepared, packaged, stored, and shipped in accordance with instructions in the "Field Operations Manual for Resource Contaminant Assessment" (Hickey and others, 1984) of the U.S Fish and Wildlife Service.

A minimum of 25 randomly selected roots and meristems of sorrel and spiked bulrush, two obligate water plants, were collected for each composite sample. The only composite sample of sago pondweed was collected from Trifolium/Vail Drains (B3). This important waterfowl food was not available at any other sampling site. Plant samples were washed of excess mud or dirt at the collection site and rewashed prior to being double bagged in polyethylene bags and frozen.

Invertebrate sampling in autumn 1986 was restricted to Asiatic freshwater clams collected at control sites B1 and B2. Other invertebrate species such as crayfish and aquatic insects were not available at this time of year. Samples of clams were collected by hand, washed in the field in a sieving bucket, and rewashed in freshwater. Composite samples of whole clams, including the shell, were divided equally and packaged separately for trace-element and organochlorine analyses. Samples for trace-element analyses were frozen and shipped in acid-washed bottles. Samples for pesticide analyses were placed in polyethylene bags, frozen, and shipped on dry ice to the analytical laboratory. The shells were removed prior to laboratory analysis of the body tissue.

Fish were collected with long-handled dipnets or small seines. Tilapia, sailfin mollies, and mosquitofish were collected because they form the major prey base for fish-eating birds and predatory fish. A minimum of 25 fish or 20 grams of whole fish was composited as a single sample. The small fish, such as the mollies and mosquitofish, were placed whole in acid-washed glass jars and frozen. The tilapia, which were as much as 10 cm (4 inches) in fork length,[2] were wrapped in aluminum foil and frozen in polyethylene bags.

Three orange-mouth corvina, approximately 70 cm fork length, were caught in a gillnet in the Salton Sea off the Alamo River delta. Fillets were cut from the lateral musculature, composited, wrapped in aluminum foil, and frozen in polyethylene bags. Corvina are a major sport fish in the Salton Sea and are eaten by both local residents and visitors. Juvenile corvina are part of the prey base of fish-eating birds.

Several species of water birds were collected to represent various feeding strategies and trophic levels. A shotgun with steel shot was used for all bird collection. Livers were dissected from each freshly killed bird, combined as a composite with two other specimens of the same species, placed in an acid-washed glass jar, and frozen for trace-element analysis. After removal of the liver for inorganic analysis, the carcass was wrapped in aluminum foil and frozen in a polyethylene bag for pesticide analysis. Bird eggs were not collected in this reconnaissance study because they were not available during the collection periods.

The black-necked stilt was selected as a sample species because it is a resident and nests in the area. It feeds primarily on invertebrates and insects. The American coot also is a resident species, with food habits similar to those of the Yuma clapper rail (*Rallus longirostris yumaiensis*), an endangered species indigenous to the area. Ruddy and shoveler ducks represent migratory waterfowl species that use the area mainly in the winter. These species are primarily invertebrate feeders and may accumulate contaminants during their winter stay. However, because they migrate through other contaminated wetlands in the Pacific flyway, they also may accumulate certain organic and inorganic contaminants from other locations--such as the Central Valley of California or the Lahontan Valley in Nevada. Resident fish-eating birds of the Salton Sea basin, including cormorants, cattle egrets, and great blue herons, were collected as an indicator of long-lived bird species highest in the food chain.

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[2]Fork length is the length between the tip of the snout to the indented part of the caudal fin.

Table 3.--*Biological samples collected from sites in the Salton Sea area, 1986-87*

[Samples are composites of three or more specimens. Number of samples: total number of samples analyzed for trace elements and for pesticides. Sites described in table 2]

Species	Sample	Sites	Number analyzed for: Trace elements	Pesticides
Vegetation				
Sorrel (*Rumex* sp.)	Roots/stems	B1-B5	9	0
Bulrush (*Scirpus* sp.)	Roots/stems	B1-B5	9	0
Sago pondweed (*Potomageton* sp.)	Whole plant	B3	1	0
Invertebrates				
Asiatic river clam (*Corbicula fluminea*)	Whole body	B1,B2,B3	6	7
Crayfish (*Procambraus clarkii*)	Whole body	B3,B4	2	1
Fish				
Mosquitofish (*Gambusia affinis*)	Whole body	B1,B3,B5	5	2
Sailfin mollie (*Poecilia latipinna*)	Whole body	B1,B2,B3,B5	5	5
Tilapia (*Tilapia zilli*)	Whole body	B1-B5	11	13
Redfin shiner (*Notropis umbratilis*)	Whole body	B2	1	1
Mudsucker (*Gillichthys mirabilis*)	Whole body	B5	1	1
Corvina (*Cynoscion xanthalus*)	Liver/muscle	B5	1	1
Birds				
Black-necked stilt (*Himantopus mexicanus*)	Liver/muscle	B2,B4,B5	4	3
American coot (*Fulica americana*)	Liver/muscle	B1,B2,B4,B5	4	4
Ruddy duck (*Oxypura jamaicensis*)	Liver/muscle	B1,B4,B5	3	3
Shoveler duck (*Anas clypeatea*)	Liver/muscle	B2,B4,B5	3	3
Cormorant (*Phalacrocorax auritus*)	Liver/muscle	B1,B5	3	3
Herring gull (*Larus argenatus*)	Liver/muscle	B5	1	1
Cattle egret (*Bulbucus ibis*)	Liver/muscle	B1,B3	2	2
Great blue heron (*Ardea herodias*)	Liver/muscle	B5	1	1

Most of the biological samples were collected in late autumn 1986. Additional samples collected in spring 1987 also were submitted for chemical analysis. The sampling in spring 1987 was prior to the availability of eggs from nesting resident species.

Analytical Methods

All water samples were analyzed by the U.S. Geological Survey, National Water Quality laboratory in Arvada, Colorado, using methods specified by Fishman and Friedman (1985) for inorganic constituents, and Wershaw and others (1987) for pesticides. Analysis of bottom-sediment samples for pesticide residue concentrations also was done by the National Water Quality Laboratory, using methods described by Wershaw and others (1987).

Concentrations of trace elements in bottom-sediment samples were determined by the U.S. Geological Survey laboratory in Denver, Colorado. Most elements were analyzed by inductively-coupled argon-plasma atomic-emission spectrometry following complete mineral digestion with strong acids. Arsenic and selenium were analyzed by hydride-generation atomic absorption, mercury by flameless cold-vapor atomic absorption, boron on the hot-water extract, and uranium and thorium by direct counting of radioactive-decay emissions. The results from all nine Department of the Interior reconnaissance study areas show that concentrations differ little for most elements between the coarse (2 mm) dry-sieved fraction and the fine-grained (smaller than 62 μm) wet-sieved fraction (Severson and others, 1987).

A total of 92 biota samples were collected in autumn 1986, and 28 additional samples were collected in spring 1987. All biota samples were analyzed at contract laboratories overseen by the Patuxent Analytical Control Facility, U.S. Fish and Wildlife Service, in Laurel, Maryland. The major types of analyses requested are listed in table 3, and results are shown in table 16 (at end of report). Trace-element analysis was done by inductively coupled plasma-emission spectroscopy after a preconcentration treatment. Hydride-generation atomic-absorption spectroscopy was used for determination of arsenic and selenium levels in tissues. A cold-vapor reduction method was used for mercury. Tissue levels were reported in micrograms per gram (μg/g), wet and dry weight, which approximates parts per million (ppm). For reporting levels of inorganic constituents, in the tables and text of this report, dry weight is used.

Residues of organochlorine pesticides and polychlorinated biphenyls (PCB isomers Arochlor 1254 and 1260) in bird-carcass, whole-fish, and invertebrate samples were measured using gas/liquid chromatography.

Quality-control procedures, including duplicate-sample analysis, spiked-reference samples, and procedural blanks, were conducted on all groups of biological samples according to quality-control standards established by the Patuxent Analytical Control Facility.

DISCUSSION OF RESULTS

Results for the reconnaissance sampling in 1986 and 1987 are presented in this section along with results from other data-sampling programs pertinent to this irrigation-drainage study.

Reconnaissance-investigation data cannot be construed to fully represent the water quality of the Imperial and Coachella Valleys, although the sites were selected to maximize their representativeness and areal coverage by sampling the major outflow from the valleys. Results from only eight tile drains in an area of 500,000 acres cannot represent the areal distribution of contaminants in the agricultural effluent, but rather provide an indication of the range in concentration and relative levels of contaminants. Coupled with the California Regional Water Quality Control Board's data, the results should provide a fairly accurate assessment of contaminant levels.

Evaluation of the chemical data generated by the reconnaissance investigation is a somewhat subjective process. A major limitation is being able to predict the probable effects of a given contaminant concentration detected in inflowing water on receiving-water biota. In addition, although Federal standards and criteria for most constituents are available, many of the standards are not applicable to specific field situations because variables such as water chemistry and bioavailability may alter the uptake and (or) response to a contaminant.

Drinking-water standards are legally enforceable levels of constituents. The drinking-water standard for selenium is 10 μg/L. However, none of the samples collected during the reconnaissance involves water destined for human consumption. Even the boron criterion of 750 μg/L for agricultural use on sensitive crops does not apply to the water sampled. Water at all sites except the control site is agricultural effluent, not water intended for irrigation Comparisons of selected constituents are made to concentrations observed at other study areas, such as Kesterson National Wildlife Refuge, where selenium contamination of both the water and wildlife has been documented and its effects described. These types of comparisons must be used with caution, however, because they involve very different sets of environmental conditions. The same caution applies to comparisons made with Volta Wildlife Management Area, which was used as a "control" for the Kesterson studies to illustrate uncontaminated water and wildlife. The Salton Sea is a saline environment, with a dissolved-solids concentration of about 41,000 mg/L (California Regional Water Quality Control Board, written commun., 1987), which means that many of the criteria for the protection of freshwater aquatic life apply to the drains, rivers, and perhaps part of the delta area, but not specifically to the Salton Sea. Also, many of the criteria stem from research conducted under laboratory rather than field conditions. Synergism and antagonism among constituents and varying environmental factors in the field can greatly alter the effects demonstrated under controlled laboratory conditions. Nevertheless, comparisons to such criteria and standards can indicate elevated concentrations of constituents and possible toxic effects. Thus, such comparisons are useful, particularly where direct evidence of toxicity is not available.

Determination of Elevated Concentrations of Constituents

The determination of elevated concentrations of constituents in water, bottom sediment, and biota is based on comparison to a variety of standards and criteria. Concentrations of constituents in water are compared primarily to criteria and standards published by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 1986a,b). Concentrations exceeding these recommended levels are considered to be elevated. The exceedance of these levels, however, does not guarantee that detrimental effects will be observed.

For tissue concentrations, the two most commonly used comparisons are levels derived from laboratory feeding studies and exceedance of the 85th-percentile value in fish from the National Contaminant Biomonitoring Program (Lowe and others, 1985). Concentrations exceeding levels in these comparisons indicate that the constituent needs to be investigated further in studies designed to detect reproductive abnormalities or other health effects. Concentrations of trace elements in bottom sediment are compared to baseline concentrations for trace elements in soils of the Western United States (R.C. Severson, U.S. Geological Survey, written commun. [using information from Shacklette and Boerngen, 1984], 1987). These comparisons are made in the following sections for constituent concentrations in water, bottom sediment, and biota.

Areal Variation of Constituents in Water

Principal Constituents and Properties

Concentrations of principal constituents and properties for samples collected in the Salton Sea area are given in table 4. Dissolved-solids concentrations for the eight tile drains sampled ranged from a low of 4,200 mg/L in tile drain 5 to a high of 26,000 mg/L in tile drain 6. The sites with higher dissolved-solids concentrations had higher chloride-to-sodium and lower sulfate-to-sodium ratios than water with lower dissolved-solids concentrations. The highest dissolved-solids concentration, 34,000 mg/L, was in the Salton Sea composite. The sodium-to-dissolved-solids ratio was fairly constant, at about 20 percent, for all sites except the Salton Sea. The sodium-to-dissolved-solids ratio in the Salton Sea, at 28 percent, was slightly higher than at other sites. Chloride generally dominates the anions in the water that has the higher dissolved-solids concentrations. Chloride constitutes 41 percent of the ions in the Salton Sea in comparison with about 20 percent for most of the sites that have lower dissolved-solids concentrations, except the New River. Chloride in the New River is about 34 percent, possibly reflecting the contribution of sewage from Mexicali. Higher relative concentrations of sodium, chloride, and sulfate in more saline waters are the result of the greater solubility of these ions. In the Salton Sea, concentrations of calcium and sulfate apparently are at or near levels that will cause the ions to combine to form gypsum (Hely and others, 1966), hence limiting the solubility of sulfate in the Salton Sea.

Table 4.--*Concentrations of major dissolved constituents in water samples, Salton Sea area, 1986*

[Specific conductance in microsiemens per centimeter at 25 degrees Celsius, pH in standard units, temperature in degrees Celsius. Concentrations in milligram per liter or parts per million on dry-weight basis; --, no data]

Site	Date	Specific conductance	pH	Temperature	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Alkalinity (as $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids
Tile drain 1	08-14-86	28,400	7.1	28.0	1,300	810	4,400	38	280	3,700	9,400	0.4	14	20,000
Tile drain 2	08-14-86	7,120	7.3	27.5	370	320	1,100	15	480	2,800	780	.8	20	5,600
Tile drain 3	08-14-86	32,200	6.8	25.0	1,800	820	3,800	35	240	2,000	11,000	.2	12	20,000
Tile drain 4	08-14-86	5,800	7.4	26.0	370	150	850	13	390	2,200	660	.5	20	4,500
Tile drain 5	08-14-86	5,610	7.2	--	310	160	810	7	370	1,900	740	1.4	26	4,200
Tile drain 6	08-14-86	35,100	7.1	--	920	1,300	5,800	65	350	5,700	12,000	.3	15	26,000
Tile drain 7	08-14-86	6,640	7.3	--	290	160	970	20	310	2,000	990	1.1	18	4,800
Tile drain 8	08-14-86	8,290	6.9	--	440	250	1,300	10	530	3,500	820	.5	22	6,700
Alamo River at outlet	08-12-86	3,540	8.1	30.0	170	90	460	11	220	830	560	.6	13	2,300
New River at outlet	08-12-86	4,520	8.0	30.0	180	86	630	15	230	740	930	.6	18	2,700
Trifolium Drain 1	08-12-86	3,630	8.0	30.0	120	84	510	17	320	900	480	1.0	22	2,300
Salton Sea composite	08-13-86	48,300	8.5	30.0	600	1,200	9,400	190	180	8,400	14,000	1.7	10	34,000

Table 5.--*Concentrations of trace elements in water samples, Salton Sea area, 1986*

[Concentrations in micrograms per liter or parts per billion. <, less than analytical detection limit]

Site	Date	Arsenic (As)	Barium (Ba)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Mercury (Hg)	Molybdenum (Mo)	Nickel (Ni)	Selenium (Se)	Silver (Ag)	Vanadium (V)	Zinc (Zn)
Tile drain 1	08-14-86	1	100	3,400	2	<1	10	100	<5	2,900	0.3	25	6	55	1	40	40
Tile drain 2	08-14-86	3	100	1,800	<1	<1	10	50	<5	540	.2	30	11	24	<1	20	30
Tile drain 3	08-14-86	1	200	3,100	2	<1	4	140	<5	130	.2	20	3	120	28	100	70
Tile drain 4	08-14-86	1	<100	1,100	<1	<1	5	30	<5	340	.2	28	4	14	<1	17	30
Tile drain 5	08-14-86	1	100	1,200	<1	<1	11	30	<5	40	<.1	36	3	7	<1	17	20
Tile drain 6	08-14-86	4	100	3,500	1	5	8	140	<5	50	.2	35	1	300	12	100	40
Tile drain 7	08-14-86	2	100	2,400	<1	<1	6	40	<5	50	<.1	58	<1	25	<1	38	20
Tile drain 8	08-14-86	1	200	1,700	<1	<1	4	50	<5	20	<.1	15	1	26	<1	22	20
Alamo River at outlet	08-12-86	5	100	680	2	<1	4	30	<5	<10	<.1	21	3	9	<1	17	20
New River at outlet	08-12-86	8	200	1,000	<1	<1	3	30	<5	10	<.1	4	3	4	<1	29	30
Trifolium Drain 1	08-12-86	4	100	1,300	2	<1	5	60	<5	40	<.1	24	4	6	<1	15	30
Salton Sea composite	08-13-86	9	300	11,000	<1	<1	1	160	<5	60	<.1	10	1	1	<1	100	70

Trace Elements

Trace-element concentrations were determined for 12 agricultural-drainwater samples collected in the Imperial Valley. Water samples were collected from eight tile drains (described in "Selection of Sampling Sites" section) and from four additional sites: the New and Alamo Rivers at their outlets, Trifolium Drain 1, and a composite sample from the Salton Sea near the Alamo River delta.

Selenium.--Prior to the reconnaissance sampling, selenium was considered the main element of concern in the Salton Sea area on the basis of a review of available water-quality data and the concern resulting from San Joaquin Valley selenium investigations. According to "Ambient Water-Quality Criteria for Selenium--1987" (U.S. Environmental Protection Agency, 1987, p. 34): "Except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of selenium does not exceed 5 μg/L more than once every 3 years on the average, and if the 1-hour average concentration does not exceed 20 μg/L more than once every 3 years on the average." For the reconnaissance investigation, 10 of the 12 water samples collected exceeded the 5 μg/L criterion, and six of the samples exceeded the 20 μg/L criterion (table 5 and fig. 11). Selenium concentrations greater than the 20 μg/L criterion are restricted to tile-drain effluent (see fig. 11). The maximum selenium concentration of 300 μg/L was detected in tile drain 6, on the east side of the Imperial Valley, southeast of Calipatria (see fig. 1). The minimum concentration of 1 μg/L was detected in the composite sample from the Salton Sea. The median selenium concentration for the 12 samples was 19 μg/L, with 25th- and 75th-quartile values of 6 and 48 μg/L, respectively. Selenium concentrations exceeded 100 μg/L in only two samples, both from tile drains.

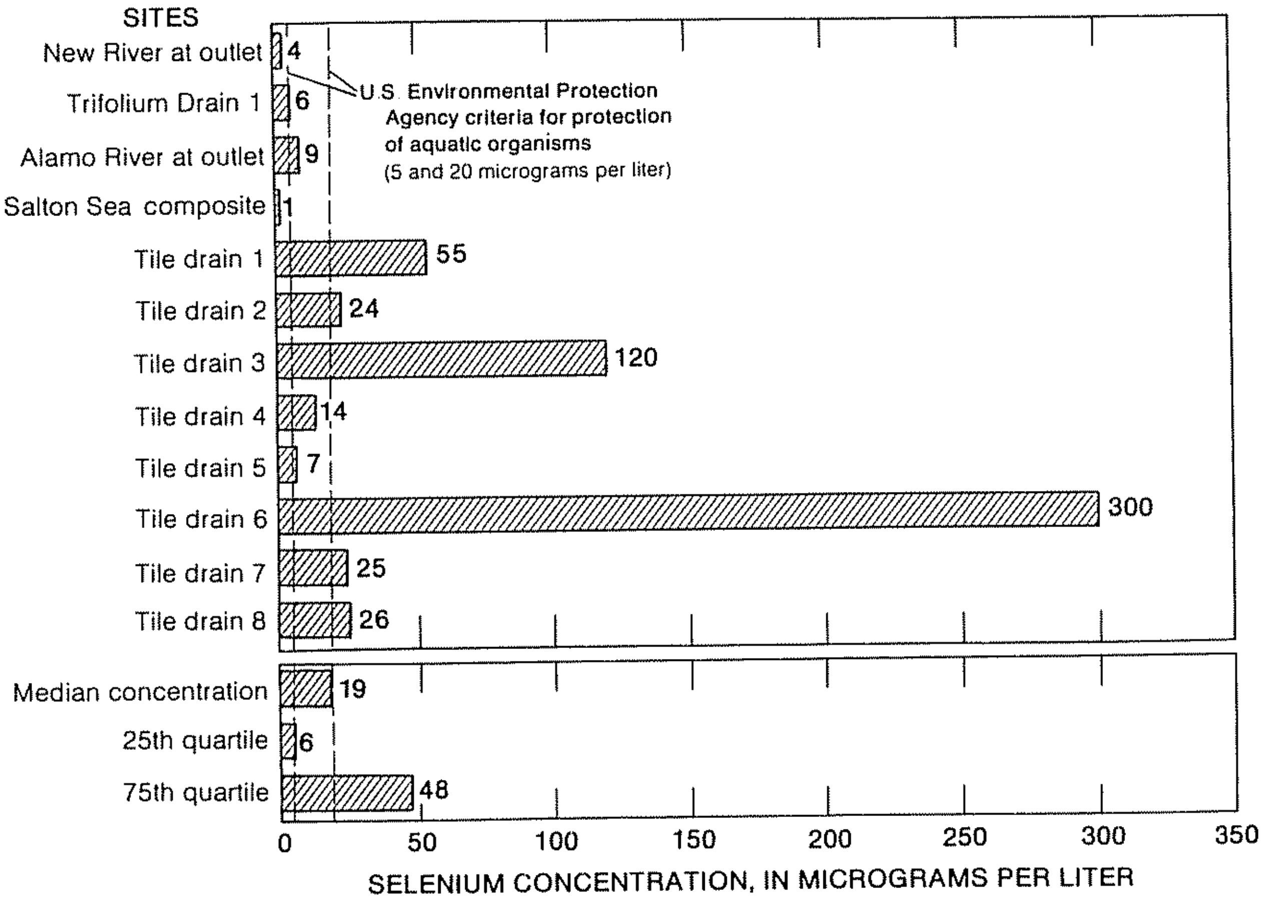

FIGURE 11. -- Selenium concentration in water samples from Salton Sea area, 1986.

The Regional Board collected tile-drain samples for trace-element analysis in June 1986. The median selenium concentration for the Regional Board's 119 samples was 25, with a minimum of 1 and a maximum of 267 $\mu g/L$ (see fig. 12) (California Regional Water Quality Control Board, written commun., 1986). These results are similar to those of the reconnaissance investigation, in which the median concentration for the eight tile-drain samples is 25, with a minimum of 7 and a maximum of 300 $\mu g/L$ (table 5).

No distinct patterns are apparent in the areal distribution of selenium concentrations in tile-drain effluent indicated by the 119 data points from the Regional Board's 1986 sampling. Adjacent to the southeastern end of the Salton Sea is an area of elevated selenium concentrations. However, elevated selenium concentrations also are found in tile drains in other parts of the Imperial Valley. The results from the reconnaissance investigation and from the Regional Board's sampling confirm the hypothesis that selenium is an element of concern in the Salton Sea area.

By comparison, Presser and Barnes (1985) found selenium concentrations ranging from 84 to 4,200 $\mu g/L$ in sumps draining fields in the western San Joaquin Valley. Deverel and others (1984) sampled shallow wells, farm drain sumps, and collector drains (130 samples in all) in 1984 and found selenium concentrations ranging from less than 1 to 3,800 $\mu g/L$, with a median concentration of 6 $\mu g/L$. Water in the San Luis Drain at its Kesterson terminus contained 330 $\mu g/L$ selenium in an August 1983 sample and 280 $\mu g/L$ in a December 1983 sample. These selenium concentrations in the San Joaquin Valley can be compared with selenium concentrations of only 4 and 9 $\mu g/L$, respectively, at the New and Alamo River outlets to the Salton Sea. The Volta Drain, which discharges into the San Luis Wasteway downstream of the Delta-Mendota Spillway, contained selenium at a concentration less than 2 $\mu g/L$ (Presser and Barnes, 1985). The San Luis Wasteway is the main source of surface-water inflow to the Volta Wildlife Management Area (VWMA). The VWMA has become one of the main comparative test or control areas for selenium contamination in the San Joaquin Valley because it receives little subsurface drainage (Presser and Barnes, 1984, p. 5).

Other trace elements.--Concentrations of other trace elements also are given in table 5. The median arsenic concentration for the 12 reconnaissance water samples was 2.5 $\mu g/L$. A minimum concentration of 1 $\mu g/L$ was observed at several of the drain sites, and the maximum concentration of 9 $\mu g/L$ was detected in the Salton Sea composite.

Barium concentrations, with a median and minimum of 100 $\mu g/L$ (detection limit) and a maximum of 300 $\mu g/L$, showed little variation among the 12 samples.

For boron, an element of concern in the study area, the median concentration was 1,750 $\mu g/L$, with a minimum of 680 $\mu g/L$ in the Alamo River at the outlet and a maximum of 11,000 $\mu g/L$ in the Salton Sea composite (fig. 13). The 25th-quartile value for boron was 1,120 $\mu g/L$ and the 75th quartile was 3,150 $\mu g/L$. The median boron concentration of 1,750 $\mu g/L$ is elevated in comparison with the 750 $\mu g/L$ criterion (U.S. Environmental Protection Agency, 1986a) for the protection of sensitive agricultural crops. However, all the water sampled was irrigation drainage, not water for irrigation of crops. The high concentrations of boron in the Salton Sea are attributable to evaporative concentration. The boron concentration of 11,000 $\mu g/L$ in the Salton Sea is below any levels currently known to cause reproductive effects in waterfowl or fish.

Cadmium and chromium concentrations were low and showed little variation. Chromium at 5 $\mu g/L$ was detected in the sample from tile drain 6, which also had a selenium concentration of 300 $\mu g/L$. The remaining chromium concentrations were less than the analytical detection limit of 1 $\mu g/L$.

Copper concentrations also were low and showed little variation in concentration. The median copper concentration was 5 $\mu g/L$, with a minimum of 1 $\mu g/L$ in the Salton Sea composite and a maximum of 11 $\mu g/L$ in tile drain 5. Iron concentrations ranged from a low of 30 $\mu g/L$, at several sites, to a high of 160 $\mu g/L$ for the Salton Sea composite. The median concentration was 50 $\mu g/L$. All lead concentrations were less than 5 $\mu g/L$.

Manganese concentration varied widely. The minimum concentration of less than 10 $\mu g/L$ was detected at the Alamo River at the outlet. The maximum concentration of 2,900 $\mu g/L$ was in tile drain 1, a sump located outside the entrance to the Salton Sea National Wildlife Refuge and adjacent to a geothermal pipeline. Manganese concentrations were at or below the detection limit of 10 $\mu g/L$ at the New and Alamo River outlets

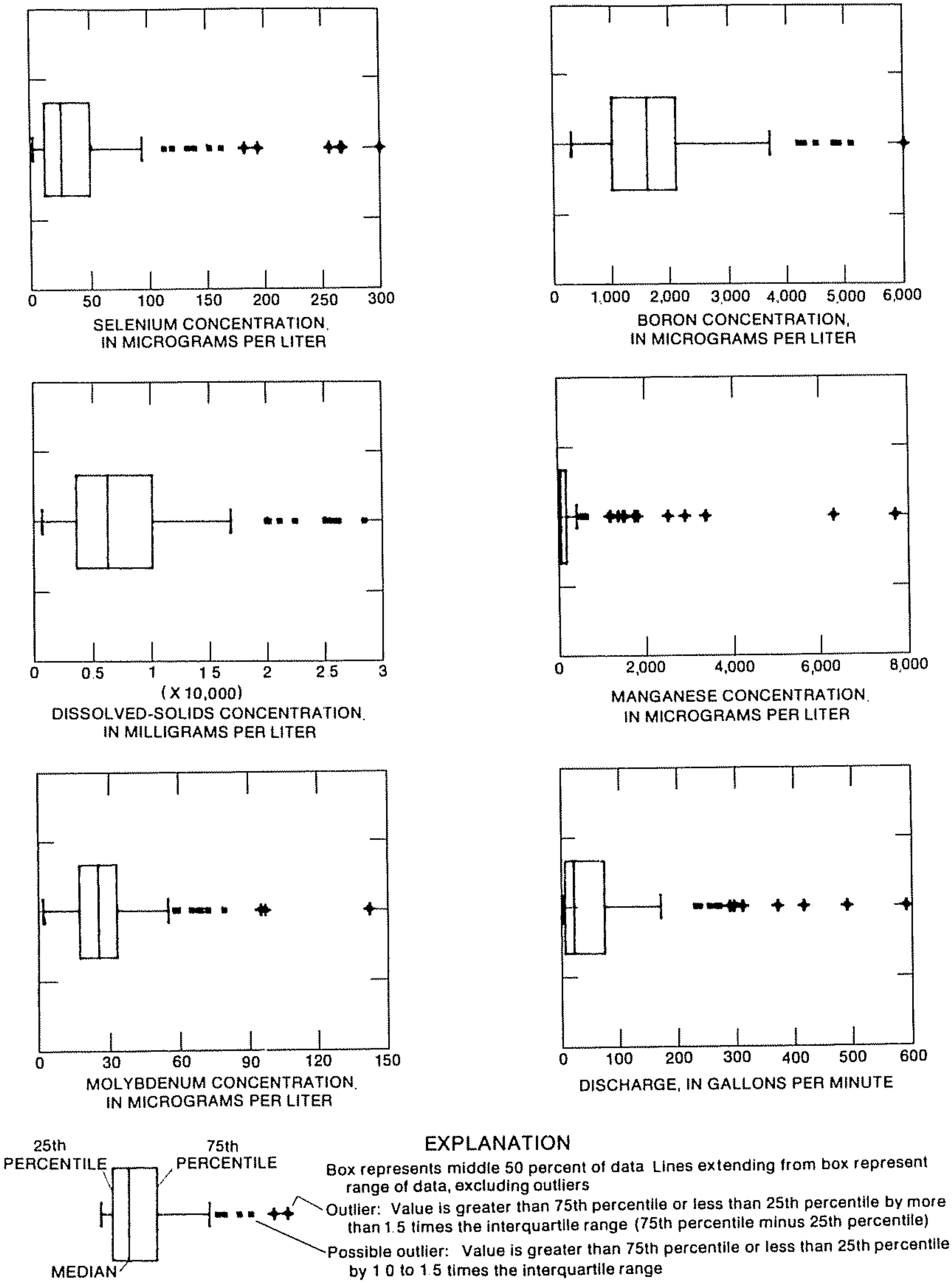

FIGURE 12.--Water discharge and selected water-quality constituents for Salton Sea area, 1986. Data from California Regional Water Quality Control Board, Colorado River Basin Region (P. A. Gruenberg, written communication, 1986)

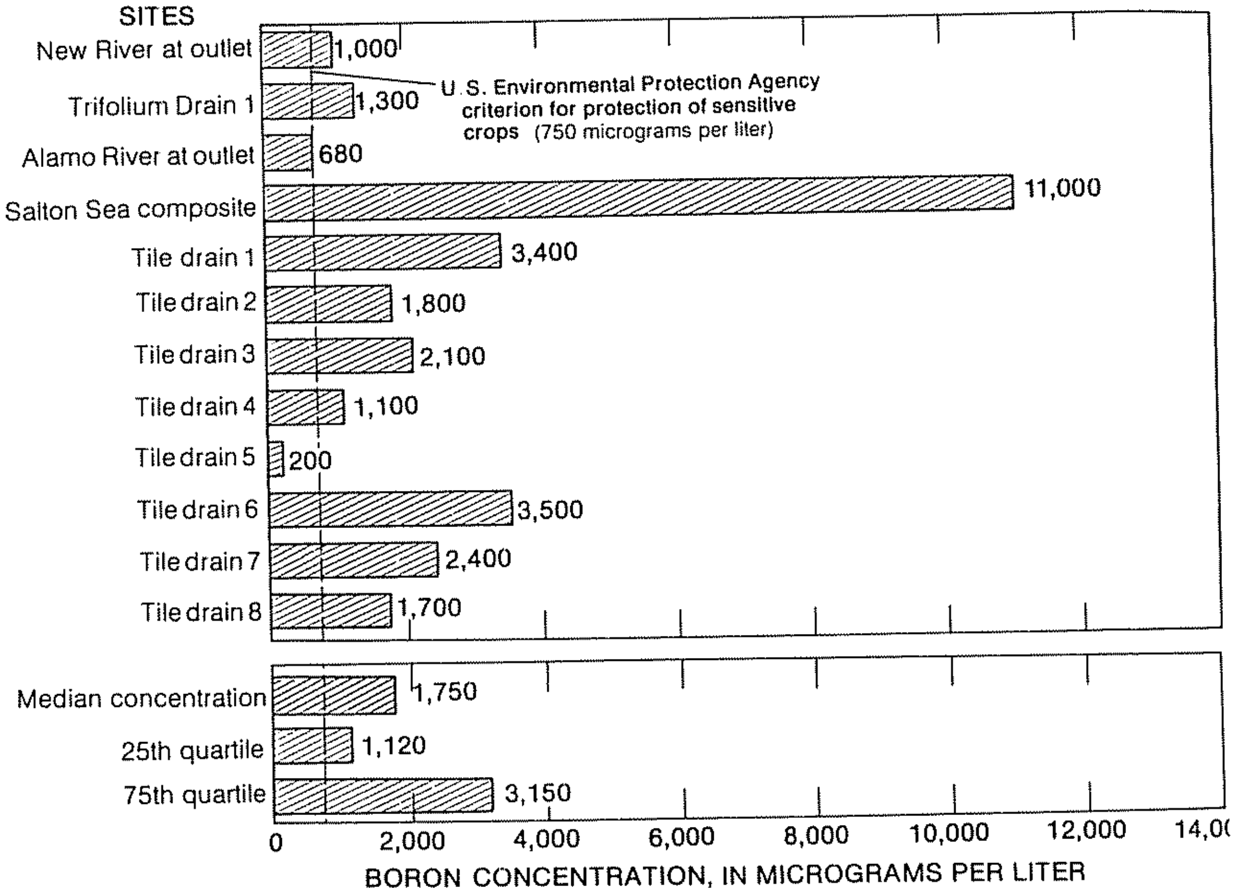

FIGURE 13. -- Boron concentration in water samples from Salton Sea area, 1986.

to the Salton Sea and 60 $\mu g/L$ in the Salton Sea composite. The drinking-water limit for manganese is 50 μg, and the National Academy of Sciences and National Academy of Engineering (1973) suggests a maxim concentration of 100 $\mu g/L$ for protection of a marine environment.

Molybdenum ranged from a low of 4 $\mu g/L$ in the New River at the outlet to a high of 58 $\mu g/L$ in drain 7. The median concentration was 24 $\mu g/L$, with 25th- and 75th-quartile values of 16 and 34, respectiv Nickel concentrations were low and showed little variation in concentration; the 25th- and 75th-quartile val were 1 and 4 $\mu g/L$.

Detectable silver concentrations probably were anomalous in that silver usually is not detected agricultural drainage. All concentrations were 1 $\mu g/L$ or less, except for concentrations of 28 and 12 $\mu g/l$ tile drains 3 and 6, respectively. These values very likely are analytical errors or the result of sam contamination. These two sites had high specific conductance, 32,200 and 35,100 $\mu S/cm$, and also had the highest selenium concentrations.

The median concentration of vanadium was 25.5 $\mu g/L$. The lowest concentration of 15 $\mu g/L$ detected at Trifolium Drain 1, and the highest concentration of 100 $\mu g/L$ was detected at several sites. 25th- and 75th-quartile values were 17 and 85 $\mu g/L$, respectively.

Zinc concentrations ranged from 20 μg/L, at several sites, to 70 μg/L in tile drain 3 and in the Salton Sea composite. The U.S. Environmental Protection Agency (1986a) recommends that zinc concentrations not exceed 120 μg/L as a 24-hour average in order to protect freshwater aquatic life. The criterion to protect saltwater aquatic life is an average concentration of 95 μg/L over 24 hours.

Mercury concentrations showed little variation, ranging from less than the analytical detection limit of 0.1 μg/L to a maximum concentration of 0.3 μg/L.

Pesticides and Other Organic Compounds

Water samples were collected from eight tile drains in the Imperial Valley to determine the concentrations of volatile organic compounds such as D-D (mixture 1,3-dichloropropene, 1,2-dichloropropane, and 2,3-dichloropropene), EDB (ethylene dibromide), and DBCP (dibromochloropropane). Compounds included nematocides or soil fumigants and carriers for non-water-soluble pesticides. These compounds were not detected.

Water samples also were collected at four sites to determine concentrations of organophosphorus and other pesticides (see table 6 for compounds analyzed). DEF (S,S,S-Tributyl phosphorotrithioate), a translocated foliar herbicide, was detected at a concentration of 0.06 μg/L at two sites. The aryloxyalkanoic acid herbicide 2,4-D (2,4-dichlorophenoxy acetic acid), a selective herbicide effective in destroying dicotyledonous plants but well tolerated by many monocotyledonous crops, was detected at three of the four water-collection sites (table 6). The highest 2,4-D concentration of 2.6 μg/L was found in the Alamo River at the outlet. Silvex was detected at the Salton Sea site.

Table 6.--*Concentrations of selected pesticides in water samples, Salton Sea area, 1986*

[Concentrations in micrograms per liter or parts per billion. <, less than indicated detection limit]

Site	DEF	2,4-D	Silvex
Alamo River at outlet	<0.01	2.6	<0.01
New River at outlet	<.01	.32	<.01
Trifolium Drain 1	.06	<.01	<.01
Salton Sea composite	.06	.30	.04

Other compounds for which analyses were performed but for which concentrations were at or below detection limits:

Propazine	Prometone	Diazinon	Ethyl trithion
Methomyl	Prometryne	Methyl parathion	Methyl trithion
Propham	Ethion	Atrazine	Cynazine
Simetryne	Malathion	2,4,5-T	2,4-DP
Simazine	Parathion	Sevin	Ametryne

Areal Variation of Constituents in Bottom Sediments

Trace Elements

Selenium.--Selenium concentrations in bottom sediments were determined for 17 samples collect in drains and rivers in the Coachella and Imperial Valleys. The highest selenium concentration of 3.3 mg/kg w in the Salton Sea composite (table 7 and fig. 14). The 75th-quartile value for selenium was 1.2 mg/kg, whi is less than the 1.4 mg/kg upper limit of the 95-percent baseline concentration for soils in the Western Unit States (table 8). The lowest concentration of 0.1 mg/kg was detected at the Whitewater River upstream fro Highway 111. This site was dry when sampled. Particle-size analysis indicated that only 4 percent of t sediments were in the <0.125 mm fraction (table 9). The median selenium bottom-sediment concentration 0.7 mg/kg for the reconnaissance is within the baseline range for soils in the Western United States (table The spread from 25th to 75th quartile is only 0.8 mg/kg. Selenium concentrations at three major outlet sites the Salton Sea--New River at outlet, Alamo River at outlet, and Whitewater River at outlet--at 0.6, 0.4, and mg/kg, respectively, were low in comparison with the Salton Sea composite.

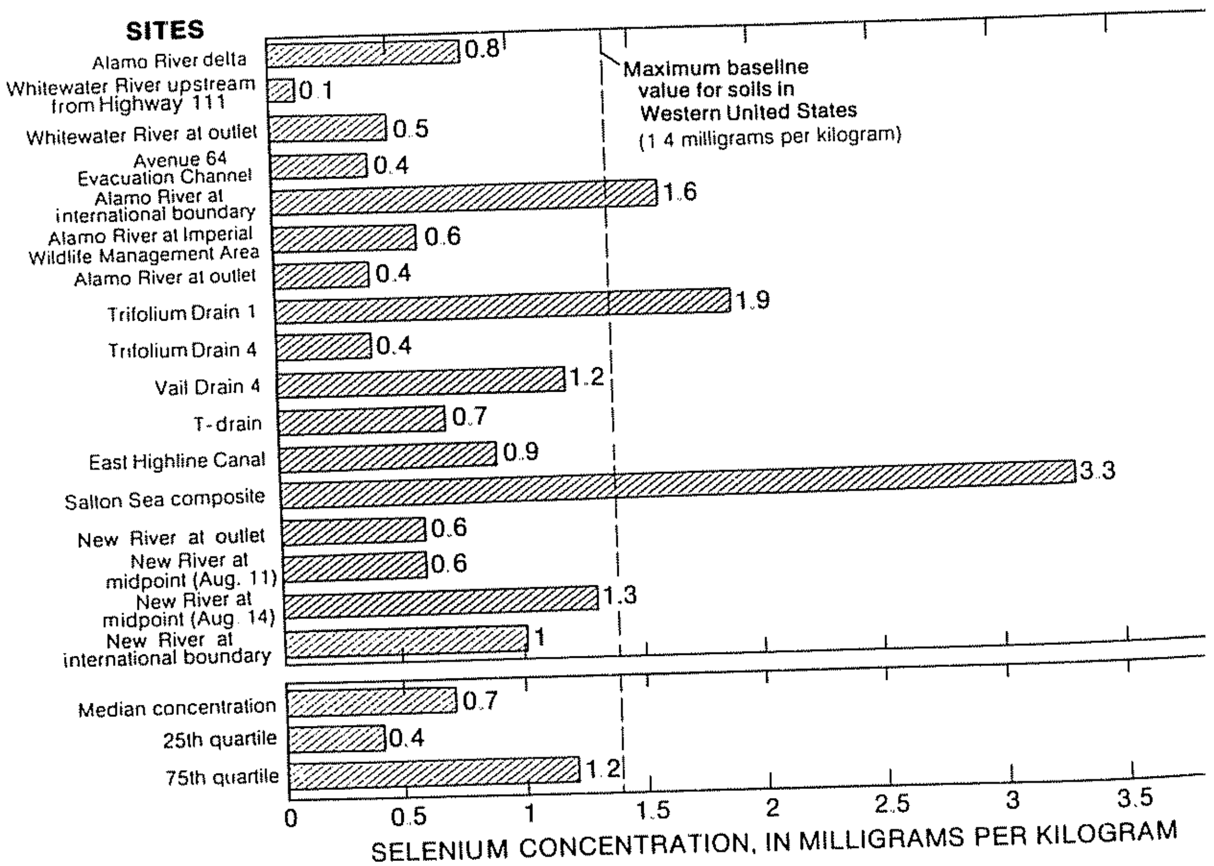

FIGURE 14. -- Selenium concentration in bottom-sediment samples from Salton Sea area,

Table 7.--*Concentrations of trace elements in bottom sediments, Salton Sea area, 1986*

[Concentrations in milligrams per kilogram or parts per million. <, less than analytical detection limit; --, not applicable]

Site No.	Site name	Arsenic (As)	Selenium (Se)	Silver (Ag)	Barium (Ba)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Lead (Pb)	Molybdenum (Mo)	Nickel (Ni)	Vanadium (V)	Zinc (Zn)	Thorium (Th)	Uranium (U)
1	East Highline Canal	4.5	0.9	<2	690	<2	50	23	28	<2	22	60	70	12.7	5.9
2	Alamo River at international boundary	6.3	1.6	<2	510	<2	58	26	21	<2	26	77	97	12.2	4.8
3	New River at international boundary	6.3	1.0	<2	550	<2	64	56	52	2	26	74	120	9.9	4.9
4	Alamo River at Imperial Wildlife Management Area	5.6	.6	<2	550	<2	53	25	20	<2	23	67	68	7.9	4.0
5	New River at midpoint														
	08-11-86	5.4	.6	<2	580	<2	63	30	23	<2	25	77	75	10.6	6.1
	08-14-86	11.0	1.3	<2	780	<2	73	27	25	2	35	96	120	12.0	7.5
6	Alamo River at outlet	6.3	.4	<2	520	<2	62	30	21	<2	28	83	89	10.5	3.8
6a[1]	Alamo River delta	5.5	.8	<2	510	<2	54	24	17	<2	24	66	70	11.1	3.8
7	New River at outlet	4.7	.6	<2	720	<2	70	23	22	<2	22	82	71	19.2	7.7
8	Trifolium Drain 1	5.8	1.9	<2	550	<2	53	28	20	<2	24	72	78	9.0	4.4
9	Trifolium Drain 4	5.6	.4	<2	590	<2	56	21	17	<2	22	68	67	9.5	4.4
10	Vail Drain 4	7.2	1.2	<2	500	<2	53	30	20	<2	25	70	72	9.6	3.5
11	T-drain	7.6	.7	<2	550	<2	57	37	21	<2	26	83	77	9.5	4.7
12	Whitewater River upstream from Highway 111	2.4	.1	<2	690	<2	81	34	21	<2	30	140	110	56.0	14.6
13	Whitewater River at outlet	5.0	.5	<2	710	<2	210	64	30	3	170	130	510	18.9	5.5
14	Avenue 64 Evacuation Channel at Highway 195	4.4	.4	<2	620	<2	75	61	22	2	42	120	130	21.3	5.1
15	Salton Sea composite	8.8	3.3	<2	480	<2	52	26	18	4	24	70	79	9.8	7.9
	Median	5.6	.7	--	550	--	58	28	21	--	25	77	78	10.6	4.9
	Minimum	2.4	.1	--	480	--	50	21	17	--	22	63	67	7.9	3.5
	Maximum	11.0	3.3	--	780	--	210	64	52	--	170	140	510	56.0	14.6
	25th quartile	4.8	.4	--	515	--	53	24	20	--	24	69	70	9.5	4.2
	75th quartile	6.8	1.2	--	690	--	72	36	24	--	29	89	115	15.8	6.8

[1]Site 6a was located immediately downstream from site 6.

Table 8.--*Geochemical baselines for soils from the Western United States*

[Concentrations in milligrams per kilogram, dry weight. Detection ratio: number of samples in which the element was found in measurable concentrations to number of samples analyzed. Baseline: expected 95-percent range; <, less than; --, not detected. From Severson and others (1987); modified from Shacklette and Boerngen (1984)]

Constituent	Detection ratio	Geometric mean	Geometric deviation	Baseline	Observed range
Arsenic	728:730	5.5	1.98	1.2-22	<0.1-97
Barium	778:778	580	1.72	200-1,700	70-5,000
Boron	506:778	23	1.99	5.8-91	<20-300
Cadmium	--	--	--	--	--
Chromium	778:778	41	2.19	8.5-200	3-2,000
Copper	778:778	21	2.07	4.9-90	2-30
Lead	712:778	17	1.80	5.2-55	<10-700
Manganese	777:777	380	1.98	97-1,500	30-5,000
Mercury	729:733	.046	2.33	0.0085-0.25	<0.01-4.6
Molybdenum	57:774	.85	2.17	0.18-4.0	<3-7
Nickel	747:778	15	2.10	3.4-66	<5-700
Selenium	590:733	.23	2.43	0.039-1.4	<0.1-4.3
Silver	--	--	--	--	--
Thorium	195:195	9.1	1.49	4.1-20.0	2.4-31.0
Uranium	224:224	2.5	1.45	1.2-5.3	0.68-7.9
Vanadium	778:778	70	1.95	18-270	70-500
Zinc	766:766	55	1.79	17-180	10-2,100

Other trace elements.--Arsenic concentrations were well within the baseline range for soils in the Western United States. The median concentration for the reconnaissance samples was 5.6 mg/kg, which can be compared with a geometric mean of 5.5 from table 8. The maximum concentration of 11 mg/kg was detected at the New River at midpoint August 14, 1986. A sample collected 3 days earlier had a concentration of 5.4 mg/kg, showing possible variation due to sampling. The particle-size distribution for these two samples indicates that the August 11 sample was composed of sediment having only 5 percent of the material in the less-than-0.062-mm fraction in comparison with 29 percent for the August 14 sample (table 9). Trace-element analyses were done on the less-than-0.062-mm fraction. The minimum concentration of 2.4 mg/kg was detected at the Whitewater River upstream from Highway 111, where only 1 percent of the sampled material was less than 0.062 mm.

Silver and cadmium were not detected in the bottom-sediment samples; all concentrations were less than the 2 mg/kg detection limit. Molybdenum was detected in only five samples; concentrations were less than the detection limit of 2 mg/kg for 12 samples. The highest molybdenum concentration of 4 mg/kg was in the Salton Sea composite.

Barium concentrations for the reconnaissance samples fall well within the baseline range of concentrations for soils in the Western United States (tables 7 and 8). The median barium concentration was 550 mg/kg, which can be compared with a geometric mean of 580 mg/kg for the baseline data.

Chromium, nickel, vanadium, and zinc show similar distributions, in that each had its maximum or near-maximum concentration at the Whitewater River at the outlet (table 7 and figs. 15-17). The elevated concentrations at this site are not from irrigation drainage but likely are the result of industrial contamination (P.A. Gruenberg, California Regional Water Quality Control Board, Colorado River Basin Region, oral commun., 1986). The maximum detected chromium concentration of 210 mg/kg is slightly higher than the upper limit of the 95-percent baseline concentration of 200 mg/kg for soils in the Western United States. The remaining

Table 9.--*Particle-size distribution in bottom sediments, Salton Sea area, 1986*

[Expressed as weight-percent less than size fraction in millimeters]

Site No.	Site name	Size fraction 8	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002
1	East Highline Canal	--	--	100	99	98	82	40	16	5	3	2	2	2
2	Alamo River at international boundary	100	96	95	95	94	89	60	24	18	15	12	11	9
3	New River at international boundary	--	--	--	--	100	99	84	39	28	24	20	18	16
4	Alamo River at Imperial Wildlife Management Area	--	--	--	--	--	100	94	50	33	25	21	19	15
5	New River at midpoint													
	08-11-86	100	96	95	94	93	74	28	5	3	2	2	2	1
	08-14-86	--	--	--	--	100	99	83	29	15	11	10	9	8
6	Alamo River at outlet	--	--	--	100	99	96	69	32	25	22	18	16	12
7	New River at outlet	--	--	--	--	--	100	99	23	9	7	7	6	6
8	Trifolium Drain 1	--	--	100	98	90	79	66	42	32	24	19	18	13
9	Trifolium Drain 4	--	--	--	--	--	100	98	43	20	13	11	10	10
10	Vail Drain 4	--	--	--	--	--	100	98	88	63	45	36	34	27
11	T-drain at Imperial Wildlife Management Area	--	100	99	99	97	89	68	57	49	42	35	29	22
12	Whitewater River upstream from Highway 111	--	--	100	99	88	35	4	1	--	--	--	--	--
13	Whitewater River at outlet	--	--	100	98	83	37	2	0	--	--	--	--	--
14	Avenue 64 Evacuation Channel	--	100	98	95	88	59	15	7	5	4	3	2	2
15	Salton Sea composite	--	--	--	--	100	99	87	41	30	25	21	19	15

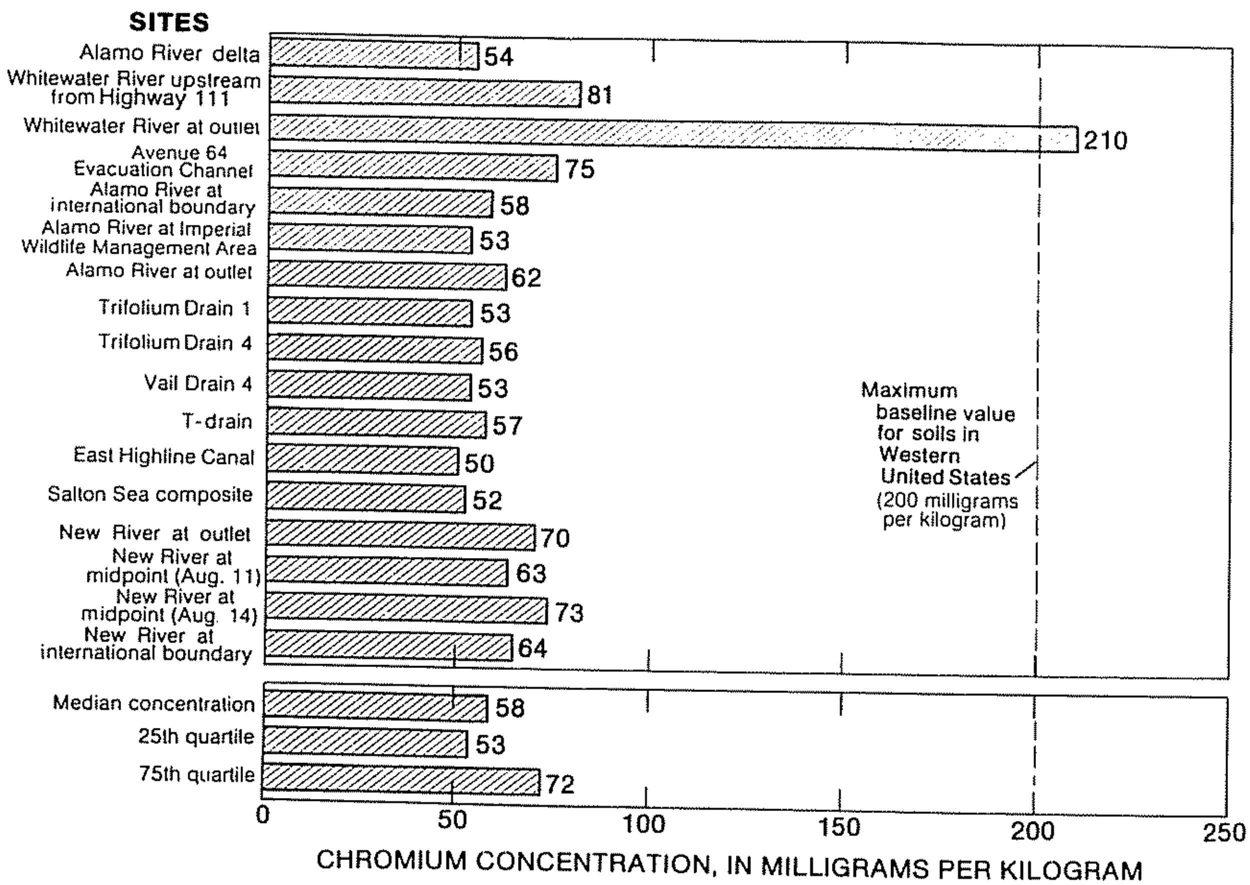

FIGURE 15. -- Chromium concentration in bottom-sediment samples from Salton Sea area, 1986.

chromium concentrations were well within the expected range, as indicated by the 75th-quartile value of 72 mg/kg. For nickel, the maximum concentration of 170 mg/kg is more than double the upper limit of the 95-percent baseline concentration of 66 mg/kg (table 8). The median concentration in the reconnaissance study of 25 mg/kg is similar to the baseline geometric mean of 15 mg/kg and within the 95-percent range.

For the three Coachella Valley sites, vanadium concentrations ranged from 120 to 140 mg/kg and were the highest of the reconnaissance study. These concentrations and the median of 77 mg/kg fall within the expected baseline range for soils in the Western United States (table 8). The zinc concentration of 510 mg/kg for the Whitewater River at the outlet, is greater than the expected baseline maximum of 180 mg/kg (table 8) for soils in the Western United States. Zinc concentrations for the remaining samples are within the expected baseline range (fig. 17).

Organochlorine Compounds

The detection of DDT metabolites in bottom-sediment samples (table 10) attest to their persistence in the environment. Because these compounds are strongly hydrophobic, concentrations detected in water usually are low. These compounds are mobilized by tailwater runoff, which carries soils with the sorbed metabolites, or by resuspension of sediment in the collector drains and rivers. DDT use was banned in the United States in 1972. Present (1986) concentrations are fairly consistent with those measured during 1978. For the reconnaissance investigation, the highest DDE concentration of 64 μg/kg was detected in the Alamo River at the outlet to the Salton Sea (site 6). This site is immediately upstream from the Alamo River delta. The next highest concentration, 57 μg/kg, was detected in Vail Drain 4 (site 10). At the Avenue 64 Evacuation Channel

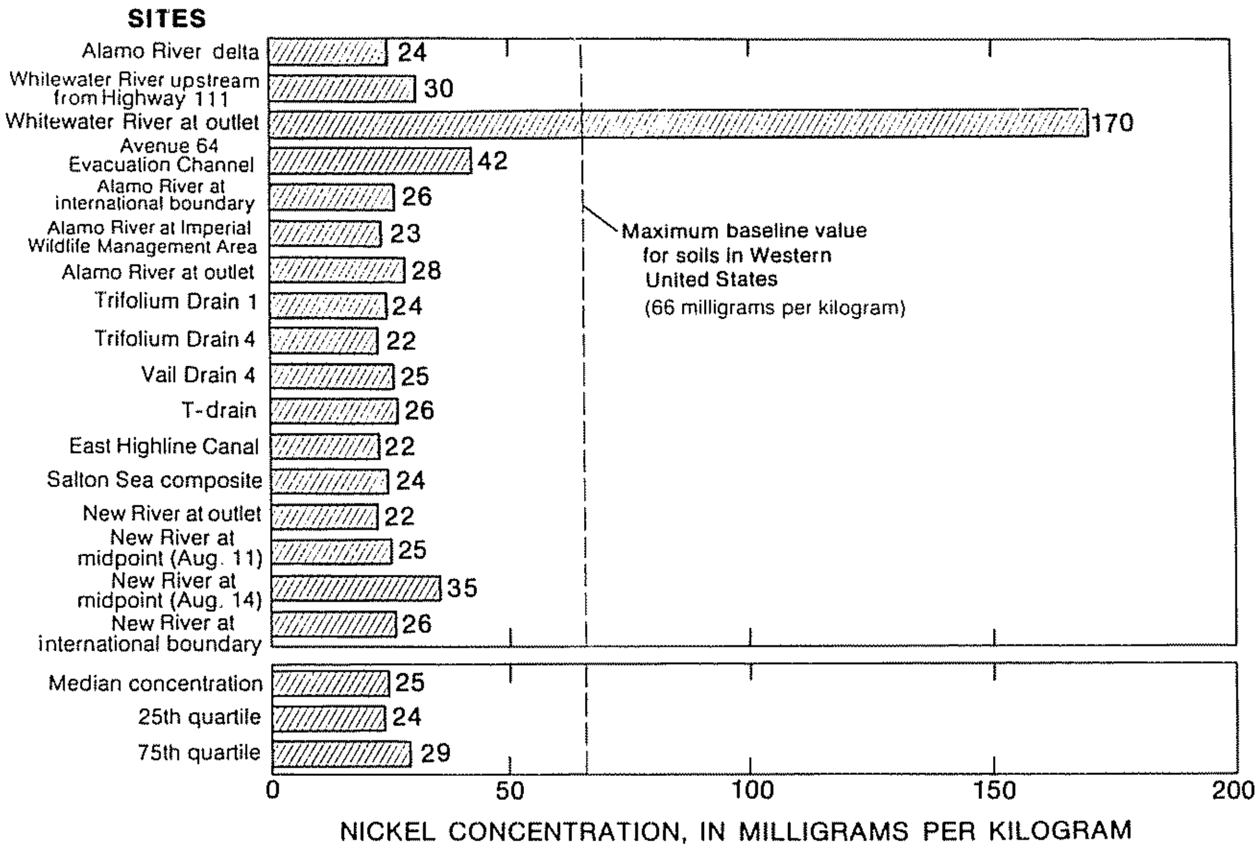

FIGURE 16. --Nickel concentration in bottom-sediment samples from Salton Sea area, 1986.

(site 14), the concentration was 56 $\mu g/kg$. Eccles (1979), in September 1977, found a DDE concentration of 67 $\mu g/kg$ at this same site, with a concurrent aqueous DDE concentration of 0.04 $\mu g/L$ and a DDE concentration of 1.3 $\mu g/L$ the previous month. Trifolium Drain 4 (site 9) also had a DDE concentration of 56 $\mu g/kg$, and Trifolium Drain 1 (site 8) had a DDE concentration of 41 $\mu g/kg$. At site 8 in 1977, Eccles found a DDE concentration of 110 $\mu g/kg$, the highest concentration of that pesticide study. A concurrent water-sample concentration of this DDT metabolite was only 0.01 $\mu g/L$.

DDD, a metabolite of DDT, also was detected in bottom sediments throughout the study area. The highest DDD concentration of 24 $\mu g/kg$ was detected in the New River at the international boundary (site 3). Detection of DDD at this site reflects either use of the compound in Mexico or resuspension of soil containing adsorbed DDD. The sample from the Alamo River at the outlet had a DDD concentration of 20 $\mu g/kg$. The lowest DDD and DDE concentrations were detected at the Whitewater River upstream from Highway 111. This site was dry when sampled and had only 1 percent of its material in the less-than-0.062-mm size fraction. Concentrations at other sites are shown in table 10.

Other organochlorine pesticides were detected in bottom sediment during the reconnaissance. Chlordane, a cyclodiene insecticide, was detected at a concentration of 20 $\mu g/kg$ in the New River at the international boundary. Chlordane concentrations at most other sites were less than the detection limit (1.0 $\mu g/kg$). Toxaphene, an insecticide heavily used on cotton in the 1970's, was detected at 40 $\mu g/kg$ in the bottom sediment of Trifolium Drain 4. Concentrations of toxaphene at other sites were 10 $\mu g/kg$ or less than the detection limit (10 $\mu g/kg$). Methoxychlor, a DDT analogue used to control ectoparasites and other insects, was detected at only one site, Vail Drain 4, at a concentration of 45 $\mu g/kg$.

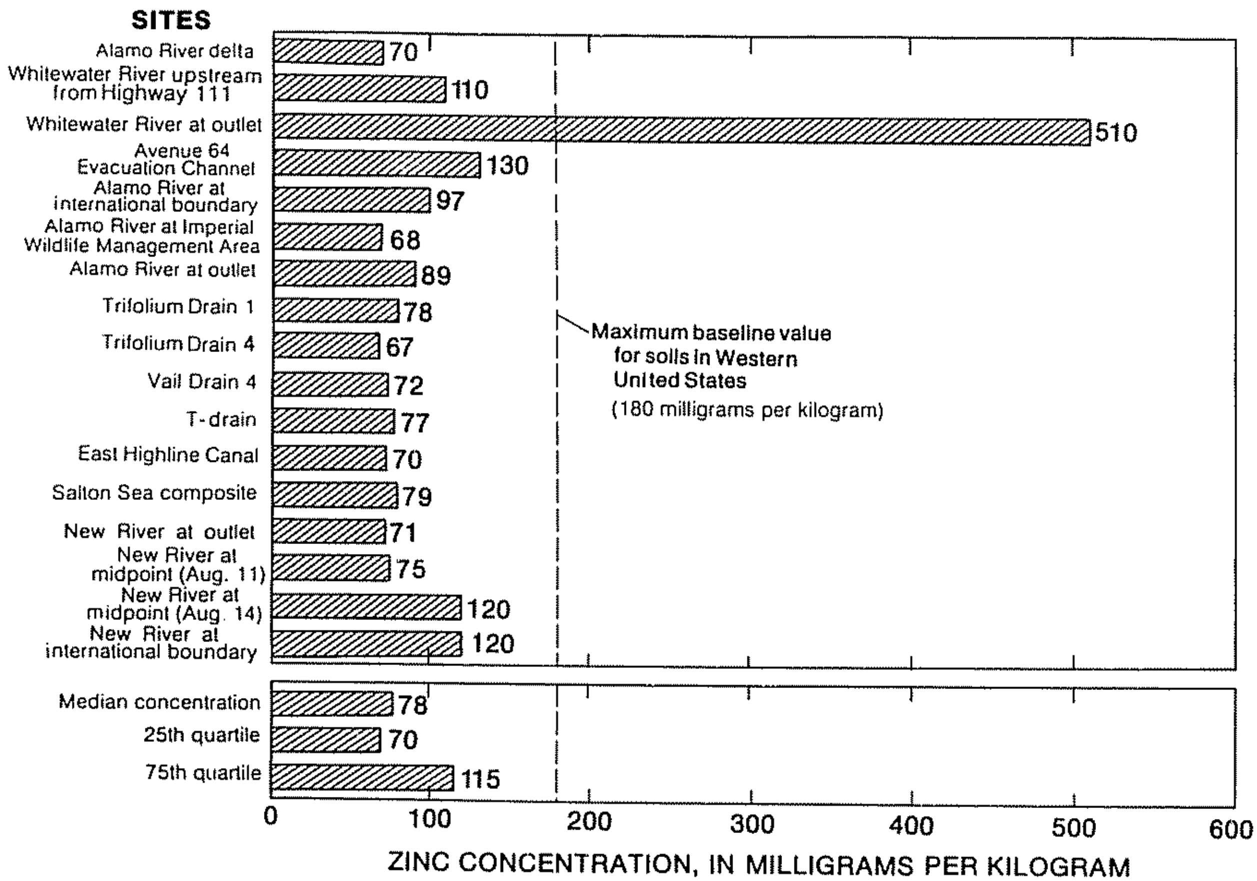

FIGURE 17.--Zinc concentration in bottom-sediment samples from Salton Sea area, 1986.

Nutrients

Concentrations of selected nutrients were determined from bottom-sediment samples collected at each site and are shown in table 11. Organic nitrogen concentrations are determined by subtracting the ammonium nitrogen values from the ammonium-plus-organic-nitrogen values. Trifolium Drain 1 and the Salton Sea composite had the two highest organic-nitrogen concentrations, 1,700 and 1,500 mg/kg, respectively. (See table 11 for the remaining concentrations.) The lowest concentration of 23 mg/kg was in the Whitewater River upstream from Highway 111, where little or no fine sediment was found in the sample. In the Salton Sea composite, organic nitrogen constituted about 0.15 percent of the fine fraction of bottom sediment.

The highest organic-carbon concentrations of 11 and 10 g/kg also were detected at Trifolium Drain 1 and in the Salton Sea composite, respectively. For these two samples, the organic-carbon content constitutes about 1 percent of the fine fraction of the bottom sediment. The lowest organic-carbon concentration, 0.3 g/kg, was in the Whitewater River upstream from Highway 111.

Total-phosphorus concentrations also were determined during the reconnaissance. The highest concentration of 1,600 mg/kg was in the New River at the outlet to the Salton sea. The lowest detected phosphorus concentration of 320 mg/kg was in the Whitewater River at outlet.

Table 10.–*Concentrations of selected pesticides and polychlorinated biphenyls (PCB) in bottom sediments, Salton Sea area, 1986*

[Concentrations in micrograms per kilogram or parts per billion, wet weight. <, less than analytical detection limits]

Site No.	Site name	Date	PCB	Chlordane	DDD	DDE	Dieldrin	Endrin	Methoxychlor	Parathion	Toxaphene
1	East Highline Canal	08-11-86	9	<1.0	2.3	18	0.2	<0.1	<0.1	--	<10
2	Alamo River at international boundary	08-11-86	9	<1.0	2.3	18	.2	<.1	<.1	--	<10
3	New River at international boundary	08-11-86	24	20	24	7.6	2.2	<.1	<.1	--	<10
4	Alamo River at Imperial Wildlife Management Area	08-12-86	<1	4.0	5.7	33	1.7	.2	<.1	--	<10
5	New River at midpoint	08-14-86	4	5.0	3.5	7.4	.3	<.1	<.1	--	<10
6	Alamo River at outlet	08-12-86	<1	<1.0	20	64	2.1	.1	<.1	<0.1	<10
7	New River at outlet	08-12-86	<1	3.0	2.4	11	.5	<.1	<.1	<.1	<10
8	Trifolium Drain 1	08-12-86	<1	<1.0	3.7	41	.5	<.1	<.1	.1	<10
9	Trifolium Drain 4	08-12-86	<1	<1.0	12	56	1.6	.1	<.1	--	40
10	Vail Drain 4	08-12-86	<1	<1.0	7.8	57	1.7	.4	45	--	<10
11	T-Drain at Imperial Wildlife Management Area	08-12-86	<1	<1.0	1.2	5.9	.1	<.1	<.1	--	10
12	Whitewater River upstream from Highway 111	08-13-86	<1	<1.0	<0.1	0.6	<.1	<.1	<.1	--	10
13	Whitewater River at outlet	08-13-86	<1	<1.0	0.2	2.0	<.1	<.1	<.1	--	<10
14	Avenue 64 Evacuation Channel	08-13-86	<1	1.0	5.8	56	<.1	<.1	<.1	--	<10
15	Salton Sea composite of four samples near biota site B5 (sampled by boat)	08-13-86	<1	<1.0	0.4	2.2	.2	<.1	<.1	<.1	<10

Other compounds for which analyses were performed but for which concentrations were at or below detection limits: PCN, aldrin, DDT, endosulfane, heptachlor, heplachlor epoxide, lindane, mirex, and perthane.

Table 11.–*Concentrations of selected nutrients in bottom sediments, Salton Sea area, 1986*

[mg/kg, milligrams per kilogram; g/kg, grams per kilogram. --, no data]

Site No.	Site name	Date	Nitrogen, NH_4, total (mg/kg as N)	Nitrogen, NH_4 + org. (mg/kg as N)	Nitrogen, organic (mg/kg as N)	Nitrogen, NO_2+NO_3 (mg/kg as N)	Phosphorus, total (mg/kg as P)	Carbon, organic (g/kg as C)	Carbon, inorganic (g/kg as C)
1	East Highline Canal	08-11-86	37	--	--	6.0	--	4	15
2	Alamo River at international boundary	08-11-86	69	390	320	3.0	1,200	5	16
3	New River at international boundary	08-11-86	67	870	800	6.0	1,000	2	21
4	Alamo River at Imperial Wildlife Management Area	08-12-86	53	750	700	3.0	1,100	4	17
5	New River at midpoint	08-14-86	26	610	580	3.0	1,300	4	14
6	Alamo River at outlet	08-12-86	17	470	450	27	1,100	1	18
7	New River at outlet	08-12-86	23	540	520	3.0	1,600	3	14
8	Trifolium Drain 1	08-12-86	79	1,800	1,700	4.0	1,200	11	21
10	Vail Drain 4	08-12-86	93	960	870	3.0	1,100	1	23
11	T-Drain at Imperial Wildlife Management Area	08-12-86	39	250	210	3.0	870	1	20
12	Whitewater River upstream from Highway 111	08-13-86	7.1	30	23	4.0	600	.3	.7
13	Whitewater River at outlet	08-13-86	6.5	110	100	7.0	320	.4	1.2
14	Avenue 64 Evacuation Channel at Highway 195	08-13-86	26	260	230	3.0	1,500	2	10
15	Salton Sea composite of four samples near biota site B5 (sampled by boat)	08-13-86	28	1,500	1,500	10	890	10	20

Radiochemical Constituents in Bottom Sediments and Water

Thorium and uranium concentrations were determined from bottom-sediment samples collected during the reconnaissance study. The thorium concentration of 56 mg/kg for the Whitewater River upstream from Highway 111 (table 7) exceeds the upper limit of the 95-percent baseline concentration of 20 mg/kg for soils in the Western United States (table 8). The thorium concentration of 21.3 mg/kg for the sample collected at the Avenue 64 Evacuation Channel at Highway 195 also exceeds this baseline concentration. The highest observed uranium concentration of 14.6 mg/kg (at the same site that had the highest thorium concentration, table 7) exceeds the upper limit of the 95-percent baseline concentration of 5.3 mg/kg for soils in the Western United States (table 8). Uranium concentrations near several other sites throughout the study area also were near or slightly above the 5.3 mg/kg limit. The Whitewater River upstream from Highway 111 was dry during sampling. The particle-size distribution at this site indicates that 98 percent of the sampled material was between 0.125 and 1 mm. This material probably is derived from erosion of granitic rocks in the San Jacinto Mountains, which may be the source of the elevated thorium and uranium.

Concentrations of radiochemical substances in water are shown in table 12. Although concentrations of gross-alpha activity are elevated at several sites, especially in the Salton Sea composite, the more specific analyses for radium-226 indicate that activity levels are below any available criteria or standards (U.S. Environmental Protection Agency, 1986a).

Table 12.--*Radiochemical constituents in water, Salton Sea area, 1986*

[μg/L, micrograms per liter; pCi/L, picocuries per liter; --, no data]

Site	Gross-beta CS-137 (pCi/L)	Gross-alpha U-natural (μg/L)	Gross-beta Sr-90 (pCi/L)	Ra-226 (pCi/L)	U as U (μg/L)
Tile drain 1	--	56	--	0.1	36
Tile drain 2	--	51	--	.2	38
Tile drain 3	3.8	7.6	3.7	.5	.4
Tile drain 4	--	37	--	.1	22
Tile drain 5	--	64	--	.3	20
Tile drain 6	--	0.4	--	.3	55
Tile drain 7	--	66	--	.1	32
Tile drain 8	--	70	--	.2	32
Alamo River at outlet	25	14	17	.2	14
New River at outlet	29	12	20	.2	9
Trifolium Drain 1	27	11	18	.2	16
Salton Sea composite	250	220	160	.3	27

Constituents in Biota

Regulatory standards and criteria have not been established for concentrations of trace elements or pesticide residues in waterfowl, fish, or lower aquatic organisms that can be used to indicate various degrees of toxicity. All biological interpretations of the current study, therefore, are subject to the limitations of extrapolating the relatively sparse toxicity data for natural systems. Certain guidelines are used for comparative purposes. These guidelines are based in part on experimental studies that relate levels of contaminants in tissues to biological effect and, in part, on field observations in more intensively studied contaminated areas such as Kesterson National Wildlife Refuge.

In this study, the primary contaminants of concern from a biological standpoint are selenium, mercury, boron, zinc, and organochlorine pesticide residues. A discussion of each of the above contaminants found in biological tissues collected from the five biological sites in the Salton Sea basin follows. Data from 120 biota samples collected and analyzed for inorganic contaminants are presented in tables 13-16. (Table 16 is at end of report.) The following elements were tested for in biological samples (and reported in table 16) but not found at levels known to have any adverse effects on fish and wildlife: arsenic, cadmium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, thallium, and vanadium. The possible effects of some constituents at apparently very low levels simply are not known. However, on the basis of known or projected information from experimental studies, these elements were not present in tissues at levels high enough to be considered detrimental to the health of the individuals sampled.

Trace Elements

Selenium.--Selenium has been identified as an important contaminant that affects the health of fish and wildlife. It has been associated with agricultural drainwater, and, when found in excessive amounts, selenium has been linked directly to mortality and reproductive failures in fish and wildlife species (Olendorf and others, 1986, 1987). Selenium has been identified in water and sediment samples from agricultural drains in the Salton Sea area at concentrations greater than those considered safe for fish and wildlife. Selenium is known to bioaccumulate in the food chain to levels that may cause adverse effects. These effects are highly variable depending on the tolerance of the individual species, the form of selenium incorporated into biochemical pathways, the age or life stage impacted, and even the presence or absence of other trace-element contaminants.

Selenium was detected at some level in almost all plant and animal samples from the Salton Sea area. Levels found in plants, invertebrates, fish, and birds from the five biological sites are presented in table 13. Total selenium is reported because analytical techniques do not differentiate between the various organic and inorganic forms or complexes of the element. Biological activity of selenium, in terms of its movement through the food chain, is a function of the form or species of the element.

The highest selenium accumulations observed in plants occurred in sago pondweed, an important waterfowl food item, collected at the Trifolium/Vail Drains (site B3) in unit 1 of the Salton Sea National Wildlife Refuge. A composite sample contained 1.1 μg/g selenium. Unfortunately, sago pondweed was not available for collection at other sampling sites because of its seasonal occurrence and drainage-ditch cleaning operations by the local irrigation district.

Spiked bulrush and sorrel are two obligate water plants also used as food by water birds. Selenium levels in the roots and meristems of these two plant species generally were low (0.20 to 0.77 μg/g, mean 0.47 μg/g) and no clear differences are evident between control and agricultural-drainage-contaminated sites. For comparison, selenium levels of 20 to 310 μg/g (mean 70 μg/g) were found in widgeongrass (*Ruppia martina*), a rooted aquatic plant, at Kesterson National Wildlife Refuge where reproductive failures and embryo malformations occurred (Ohlendorf and others, 1986). Selenium may be entering the food web of the Salton Sea Basin in some manner other than through higher plants. Planktonic uptake was not examined in this study, but it is being studied currently by other, university-based researchers. Results are not yet available.

Three composite samples of Asiatic river clams collected from the New River at Rio Bend control site (B1) in autumn 1986 had a mean value of 5.4 μg/g selenium. A single composite sample of clams from the Whitewater River delta control site (B2) also had 5.4 μg/g selenium. The only 1987 sample of clams from a drainwater-impacted site was from the Trifolium/Vail Drains (B3). This sample contained only 0.71 μg/g selenium. A second sample of clams collected from the New River at Rio Bend control site (B1) in spring 1987 also had 0.71 μg/g selenium, a dramatic decrease from the previous year's autumn collection at this same location. The decrease may be explained by the supposition that selenium may be purged from clams during spring spawning along with their sex products. Clams are food items for several species of waterfowl and thus the cycling of selenium needs further study. In contrast to the clams, composite samples of crayfish collected in spring 1987 from the Trifolium/Vail Drains (B3) and the New River delta (B4) had 3.7 and 2.5 μg/g of selenium, respectively. Neither the clams nor crayfish had levels of selenium that approached the 10 μg/g dietary level that produced abnormalities in waterfowl during laboratory experiments (Heinz and others, 1987).

Selenium levels in fish tissues were variable, depending on species and location of collection. Both mosquitofish and the sailfin mollies are topminnows that feed primarily on aquatic insects. Composite samples of whole mosquitofish from the New River at Rio Bend site (B1) contained 5.4 μg/g, and composite samples of sailfin mollies contained 6.7 and 7.7 μg/g. These levels are lower than the levels obtained from similar samples collected from the three drainwater-impacted sites (16, 7.3, 7.6, and 6.3 μg/g for mosquitofish; 9.8 and 11 μg/g for sailfin mollies). These differences indicate increased levels of selenium in resident fish at sites affected by agricultural drainwater. The mean values might have been even greater considering that the composite samples of fish from the drainwater sites were heavily dominated by fish of the 0 age class (young of the year), whereas topminnows from both age class 0 and 1 (1 to 2 years) were present in composite fish samples from the control sites. The older age classes would be expected to have accumulated more selenium (M.K. Saiki, U.S. Fish and Wildlife Service, written commun., 1988). Mosquitofish collected in selenium-contaminated drains at Kesterson National Wildlife Refuge had selenium levels of 115 to 283 μg/g (Ohlendorf and others, 1987). All samples of mosquitofish and sailfin mollies collected at both control and drainwater sites had selenium levels in excess of the 1980-81 National Contaminant Biomonitoring Program 85th-percentile concentration of 2.8 μg/g (Lowe and others, 1985).

Tilapia, an important forage fish, also were analyzed for whole-body levels of selenium because of their relatively small size (10 cm fork length) and because they are consumed as whole fish by fish-eating birds. Two composite samples from the New River at Rio Bend control site (B1) contained 8.0 and 10 μg/g selenium. These levels are almost twice the levels of 3.5 and 6.3 μg/g from two composite samples collected at the Whitewater River delta control site (B2). They are comparable to levels of 9.3 and 12 μg/g found at the Trifolium/Vail Drains site (B3), and 9.3, 12, 14, and 17 μg/g at the Alamo River delta site (B5). The presence of drainwater contamination from agricultural activity in Mexico or the movement of the fish from the contaminated lower reaches of the New River may explain these high levels. Levels of selenium in tilapia approached or exceeded levels that may be considered detrimental to reproductive success in fish-eating birds such as cormorants and herons, on the basis of extrapolation of laboratory data for mallard ducks obtained in feeding trials. These experiments demonstrated that selenium fed above 10 μg/g as selenomethionine caused abnormal embryos and poor survival (Heinz and others, 1987). Larger tilapia may be expected to contain higher levels of selenium because of bioaccumulation.

A composite sample of edible fillets (muscle) of the most popular sportfish, orange-mouth corvina, had a selenium concentration of 20.0 μg/g. This sample was collected in the Salton Sea near the Alamo River delta (site B5). No samples of corvina were obtained from control sites because the ecological requirements of the species restrict it to open-water marine habitats. This species is the top predatory fish in the system and is consumed by both local and visiting sport fishermen. Levels of selenium greater than 8 μg/g in edible parts of fish have required the issuance of a health warning by Imperial County Health Department (P.A. Gruenberg, California Regional Water Quality Control Board, Colorado River Basin Region, oral commun., 1986).

Selenium concentrations in all six species of fish (table 13) exceeded the National Contaminant Biomonitoring Program (NCBP) 1980-81 85th-percentile value of 2.8 μg/g (Lowe and others, 1985). The mean concentration of selenium in fish from the control sites was 6.2 μg/g and the range was 3.5 to 10 μg/g. The mean concentration in fish from the agricultural-drainage sites was 10.9 μg/g and the range was 4.3 to 20 μg/g.

Even though birds are quite mobile, there is evidence of selenium accumulation that correlates with the collection location, food habits, and probably age (or at least time of residence in the system). Black-necked stilts forage locally for invertebrates in shallow water. They are present during a significant part of the year and breed at the Salton Sea National Wildlife Refuge near the mouth of the Alamo and New Rivers. A composite sample of stilt livers collected at the Whitewater delta control site (B2) had 19 μg/g selenium. Similar concentrations in stilt livers were observed at sites receiving drainwater: 27 μg/g at New River delta (B4) and 20 μg/g at Alamo River delta (B5). Mean selenium concentrations of 16 μg/g (range 3.4 to 61 μg/g) were reported in American avocets, a shorebird with feeding habits similar to those of black-necked stilts, at Kesterson National Wildlife Refuge (Ohlendorf and others, 1987). A mean concentration of 54 μg/g (range 26 to 120 μg/g) selenium was found in avocet livers collected at Westfarmers evaporation ponds in the Tulare Lake basin (Schroeder and others, 1988). A high incidence of embryo deformities was found at these locations. Embryo deformities and other reproductive failures have not been documented in stilts nesting in the Salton Sea basin. Tissue levels, however, are within the range that has been associated elsewhere with a high incidence of deformity and poor hatching success.

Table 13.--*Selenium in biota, Salton Sea area, 1986-87*

[Concentrations in micrograms per gram, dry weight. <, less than indicated detection limit. --, no data. Results for each composite sample are shown separately]

Sample type	Site B1 New River at Rio Bend 1986	Site B1 1987	Site B2 Whitewater River delta 1986	Site B2 1987	Site B3 Trifolium/Vail Drains 1986	Site B3 1987	Site B4 New River delta 1986	Site B4 1987	Site B5 Alamo River delta 1986	Site B5 1987
AQUATIC VEGETATION										
Sago pondweed	--	--	--	--	1.1	--	--	--	--	--
EMERGENT WETLAND PLANTS										
Bulrush/Sorrel	<0.2	--	0.43	--	<0.2	--	<0.2	--	0.74	--
	--	--	.20	--	<.2	--	<.2	--	--	--
	--	--	--	--	--	--	.77	--	--	--
INVERTEBRATES										
Asiatic river clams	4.8	0.71	5.4	--	--	0.71	--	--	--	--
	5.1	--	--	--	--	--	--	--	--	--
	6.2	--	--	--	--	--	--	--	--	--
Crayfish	--	--	--	--	--	3.7	--	2.5	--	--
FORAGE FISH										
Mosquitofish	5.4	--	--	--	16	--	--	--	7.6	--
	--	--	--	--	7.3	--	--	--	6.3	--
Salifin mollies	6.7	--	3.7	--	9.8	--	--	--	11	--
	7.7	--	--	--	--	--	--	--	--	--
Redfin shiner	--	--	--	4.7	--	--	--	--	--	--
Tilapia	8.0	--	6.3	--	12	--	4.3	--	14	9.3
	10	--	3.5	--	9.3	--	--	--	12	--
	--	--	--	--	--	--	--	--	17	--
Mudsucker	--	--	--	--	--	--	--	--	--	7.2
Corvina	--	--	--	--	--	--	--	--	20	--
WATER BIRDS--RESIDENT										
Black-necked stilt (liver)	--	--	19	--	--	--	27	--	20	--
Coot (liver)	16	--	14	--	--	--	8.3	--	21	--
Cormorant (liver)	21	--	--	--	--	--	--	--	18	42
Cattle egret (liver)	--	6.7	--	--	--	5.2	--	--	--	--
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	15
WATER BIRDS--MIGRATORY										
Shoveler (liver)	--	--	17	--	--	--	26	--	21	--
Gull (liver)	--	--	--	--	--	--	--	--	--	14
Ruddy duck (liver)	19	--	--	--	--	--	27	--	7	--

Both shoveler and ruddy ducks feed on shallow-water benthic invertebrates. The ducks migrate into the Salton Sea basin in early autumn and leave again in spring. Livers from both species were collected in the autumn some time after their arrival. Selenium levels ranged from 7 to 27 μg/g (mean 19.5). There appears to be no appreciable difference between ducks collected from control sites and those from drainwater-receiving sites. The selenium levels found in resident coots, 8.3 to 21 μg/g, were within the same range of values. Selenium levels in livers from these three species of waterfowl were elevated and in some cases approached the levels of 22 to 175 μg/g found at Kesterson National Wildlife Refuge, where mortality and embryo deformities due to selenium have been documented (Ohlendorf and others, 1987).

Fish-eating birds also accumulated high levels of selenium. A sample of double-crested cormorants collected near the Alamo River delta had the highest level of selenium found in this study, 42 μg/g. This sample also had a high level of mercury, 27.6 μg/g. Selenium is known to be protective for mercury toxicosis (Eisler, 1987). Concentrations of selenium in livers of cattle egrets and great blue herons ranged from 5.2 to 15 μg/g.

Reproductive effects or mortality associated with selenium toxicosis have not been documented in birds at the Salton Sea, even though selenium concentrations approach levels found in birds at other wetlands contaminated by agricultural drainwater where such effects have been documented. However, selenium levels in tissues of marine and coastal vertebrates--including fish, birds, and mammals--are higher than those normally found in freshwater species. In freshwater organisms, about 36 percent of the total selenium is present as selenate, compared with 24 percent in marine species (Eisler, 1985). The Salton Sea is a marine habitat and therefore may cycle selenium in less-toxic forms.

Biological effects may or may not be present in subtle forms that have not yet been documented in either fish or wild birds. Intensive studies of important life stages of resident species may yet document such effects. On the other hand, the unique ecosystem of the Salton Sea may have adapted to elevated levels of selenium, or the ecosystem may have mechanisms that decrease the toxic effects of selenium contamination that has, in all probability, existed since irrigation-based agriculture began in the area in the early 1900's.

Mercury.--Mercury concentrations in biota are presented in table 14. Mercury was not detected in aquatic vegetation. Concentrations in invertebrates and forage fish either were below detectable levels or below the 85th-percentile concentration of 0.72 μg/g (dry-weight basis, assuming average water content of 75 percent) for fish sampled nationwide in 1980-81 as part of the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program (Lowe and others, 1985).

Mercury was detected in some samples of bird livers at levels as high as 49 μg/g. Fish-eating birds such as the cormorants and great blue herons had the highest levels of mercury (7.6 to 49 μg/g, mean 23.6 μg/g). These species are relatively long lived and migrate outside the area. Mercury may be accumulated in tissues over long periods of time. It is likely that the source of the observed high levels came from outside the Salton Sea basin because of the very low levels of mercury found in fish collected from the area.

Shoveler ducks also had relatively high levels of mercury in liver samples (2.2 to 11 μg/g, mean 5.5 μg/g). The feeding habits of the shoveler duck would promote exposure to biologically available methylated forms of mercury in the sediment. Shovelers are migratory and may have come from Carson Lake near Fallon, Nevada, where mercury from early silver mining is known to exist in the sediments. High mercury levels were found recently in shovelers from Carson Lake in a study of Lahontan Valley agricultural drainwater (Robert Hallock, U.S. Fish and Wildlife Service, written commun., 1987).

Samples of black-necked stilt livers had levels of mercury that ranged from 0.72 to 1.8 μg/g (mean 1.2 μg/g). Although most of the black-necked stilts are resident, there are some seasonally migratory segments of the population. The higher level of mercury in some stilts may be from birds that migrated from Carson Lake, Nevada.

The biological effects of mercury include acute neurotoxicity, emaciation due to loss of appetite, blindness, behavioral changes, and death. Mercury also may be embryotoxic, a teratogen, and a carcinogen (Eisler, 1987). Mercury may be stored in the tissues for long periods of time and then released into the body at times of nutritional stress. Evaluating the significance of liver mercury levels in birds in relation to observed biological effects is extremely complex and beyond the scope of this report. The levels observed in the fish-eating birds approach or exceed levels reported from birds with significant signs of subacute or chronic toxicosis (Eisler, 1987). However, the data presented in this report are for total mercury and do not account for observed

Table 14.--*Mercury in biota, the Salton Sea area, 1986-87*

[Concentrations in micrograms per gram, dry weight. <, less than indicated detection limit. --, no data. Results for each composite sample are shown separately]

Sample type	Site B1 New River at Rio Bend 1986	Site B1 1987	Site B2 Whitewater River delta 1986	Site B2 1987	Site B3 Trifolium/Vail Drains 1986	Site B3 1987	Site B4 New River delta 1986	Site B4 1987	Site B5 Alamo River delta 1986	Site B5 1987
AQUATIC VEGETATION										
Sago pondweed	--	--	--	--	<0.1	--	--	--	--	--
EMERGENT WETLAND PLANTS										
Bulrush/Sorrel	<0.1	--	<0.1	--	<.1	--	<0.1	--	<0.1	--
	--	--	<.1	--	<.1	--	<.1	--	--	--
	--	--	--	--	--	--	<.1	--	--	--
INVERTEBRATES										
Asiatic river clams	<.1	<0.1	<.1	--	--	<0.1	--	--	--	--
	<.1	--	--	--	--	--	--	--	--	--
	<.1	--	--	--	--	--	--	--	--	--
Crayfish	--	--	--	--	--	--	--	--	--	--
FORAGE FISH										
Mosquitofish	<.1	--	--	--	<.1	--	--	--	.19	--
	--	--	--	--	<.1	--	--	--	<.1	--
	--	--	--	--	--	--	--	--	<.1	--
	--	--	--	--	--	--	--	--	<.1	--
Salifin mollies	<.1	--	<.1	--	<.1	--	--	--	<.1	--
	<.1	--	--	--	--	--	--	--	--	--
Redfin shiner	--	--	--	0.16	--	--	--	--	--	--
Tilapia	<.1	--	.18	--	<.1	--	<.1	--	<.1	<0.1
	<.1	--	<.1	--	<.1	--	<.1	--	<.1	--
	--	--	--	--	--	--	--	--	<.1	--
Mudsucker	--	--	--	--	--	--	--	--	--	.46
Corvina	--	--	--	--	--	--	--	--	<.1	--
WATER BIRDS--RESIDENT										
Black-necked stilt (liver)	--	--	.72	--	--	--	1.2	--	1.8	--
Coot (liver)	.68	--	.27	--	--	--	--	--	.34	--
Cormorant (liver)	7.6	--	--	--	--	--	--	--	49	27.6
Cattle egret (liver)	--	.17	--	--	--	--	--	--	--	.10
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	10.3
WATER BIRDS--MIGRATORY										
Shoveler (liver)	--	--	2.2	--	--	--	.52	--	4.4	--
	--	--	--	--	--	--	11	--	--	--
	--	--	--	--	--	--	3.7	--	--	--
Gull (liver)	--	--	--	--	--	--	--	--	--	.13
Ruddy duck (liver)	.28	--	--	--	--	--	1.4	--	.14	--

differences in physiological injury, which may be greater with methylated forms of inorganic mercury. Additionally, selenium, a known mercury antagonist, may provide significant protection against the effects of mercury (Eisler, 1987). Selenium levels are high in the Salton Sea ecosystem, particularly in birds with high levels of mercury.

In conclusion, mercury is present in some birds at the Salton Sea, but it probably is obtained outside the area. Although some mining has occurred and is ongoing in the study area, it probably is not a potential source of mercury contamination. On the basis of an evaluation of analytical data from samples of water, sediment, and lower-food-chain items, agricultural drainwater has no link to the observed mercury.

Boron.--Boron occurs in the Salton Sea environment at slightly elevated levels. Elevated levels of boron have been associated with agricultural drainwater in other areas (Sylvester and others, 1988). The biological effects of boron on aquatic organisms are poorly understood. Boron concentrations in biota samples are presented in table 15. Preconcentration methods used during analysis of the 1987 samples preclude the accurate determination of this element. Therefore, only 1986 values appear in table 15 and were considered in this evaluation.

The highest level of boron measured in plants was 370 $\mu g/g$ in sago pondweed collected at the Trifolium/Vail Drains (B3). Sago pondweed is a major food item for migratory waterfowl. Laboratory studies by the U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, have demonstrated that embryotoxic effects occur in mallard ducks fed 1,000 $\mu g/g$ boron and that the adverse-dietary-effects level is between 300 and 1,000 $\mu g/g$ (U.S. Fish and Wildlife Service, 1987).

Levels of boron in the rooted aquatic plants bulrush and sorrel ranged from 40 to 130 $\mu g/g$ (mean 68.6 $\mu g/g$). Samples from the three drainwater-impacted sites were higher (61-130 $\mu g/g$, mean 81.3 $\mu g/g$) than the control sites (40-48 $\mu g/g$, mean 43.0 $\mu g/g$). These levels are low in comparison with mean levels reported for rooted aquatic plants from Kesterson National Wildlife Refuge (380 $\mu g/g$) and Westfarmers evaporation ponds (540 $\mu g/g$) where bird deformities and embryotoxic effects recently have been documented (Ohlendorf and others, 1986; Schroeder and others, 1988).

Levels in invertebrates and fish samples usually were below detectable limits or at relatively low levels. The significance of whole-body levels of boron in the range of 20 to 42 $\mu g/g$ in fish is not known.

Levels of boron in the livers of resident water birds ranged from below detection to 52 $\mu g/g$. The highest concentration (52 $\mu g/g$) occurred in a composite sample of coot livers from the Rio Bend control site (B1) on the New River. No apparent correlation between drainwater sites and non-drainwater sites was evident in the bird-liver data.

Liver levels of boron in migratory water birds were higher (<20 to 180 $\mu g/g$, mean 77.6 $\mu g/g$) than in resident water birds. The levels of boron observed in the livers also are within or greater than the range of values observed in mallard ducks experimentally fed boron as boric acid at a level of 1,000 $\mu g/g$. Adult liver levels in these experimental studies ranged from 6 to 74 $\mu g/g$, and reproductive effects were observed. Growth and survivability of mallard ducklings were affected when they were fed boron at a level of 1,000 $\mu g/g$. Levels of boron in duckling livers ranged from 23 to 89 $\mu g/g$ (U.S. Fish and Wildlife Service, 1987).

Boron levels in the livers of water birds collected at the Westfarmers evaporation ponds in the San Joaquin Valley, California, averaged 21 $\mu g/g$ and ranged between 16 and 81 $\mu g/g$ (Schroeder and others, 1988). Embryo deformities and death were observed at the Westfarmers pond locations. However, because of the elevated levels of other trace elements, including selenium, it would be difficult to clearly associate levels of boron found at either Westfarmers evaporation ponds or the Salton Sea with direct biological consequences such as embryotoxicity, deformities, or decreased growth and survival.

The boron levels in livers of birds from the Salton Sea are elevated, but the significance of this observation to the health of these birds is not known. The effects of selenium on bird reproduction may mask the effects of boron. Boron would need to be studied further at the Salton Sea to determine whether biological effects can be documented and whether bioaccumulation is occurring, or whether migratory birds are arriving at the Salton Sea with high levels of boron obtained elsewhere.

Table 15.--*Boron in biota, Salton Sea area, 1986*

[Concentrations in micrograms per gram, dry weight. <, less than indicated detection limit. --, no data. Results for each composite sample are shown separately]

Sample type	Site B1 New River at Rio Bend	Site B2 Whitewater River delta	Site B3 Trifolium/Vail Drains	Site B4 New River delta	Site B5 Alamo River delta
AQUATIC VEGETATION					
Sago pondweed	--	--	370	--	--
EMERGENT WETLAND PLANTS					
Bulrush/Sorrel	48	40	110	61	51
	41	--	64	130	72
INVERTEBRATES					
Asiatic river clams	52	66	--	--	--
	65	--	--	--	--
	71	--	--	--	--
Crayfish	--	--	--	--	--
FORAGE FISH					
Mosquitofish	<20	--	25	--	<20
	--	--	<20	--	<20
Salifin mollies	<20	<20	26	--	22
	<20	--	--	--	--
Redfin shiner	--	--	--	--	--
Tilapia	<20	<20	<20	<20	21
	<20	<20	24	22	42
	--	--	--	--	<20
Mudsucker	--	--	--	--	--
Corvina	--	--	--	--	<20
WATER BIRDS--RESIDENT					
Black-necked stilt (liver)	--	<20	<20	<20	36
Coot (liver)	52	22	--	--	47
Cormorant (liver)	<20	--	--	--	25
Cattle egret (liver)	--	--	--	--	--
Great blue heron (liver)	--	--	--	--	--
WATER BIRDS--MIGRATORY					
Shoveler (liver)	--	40	--	50	23
	--	--	--	48	--
	--	--	--	110	--
Gull (liver)	--	--	--	--	--
Ruddy duck (liver)	180	--	--	150	<20

Organochlorine Pesticide Residues

Fifty-two samples that included invertebrates, fish, and birds were collected and submitted to analytical laboratories for organochlorine pesticide and PCB (polychlorinated biphenyl) residue analyses.

Elevated levels of DDT and its metabolites, DDE and DDD, are suspected in some fish and waterbird samples (Linn, 1987; Mora, 1984). A finding of elevated levels would be consistent with findings of other studies in the area. However, interpretation of the data set from the reconnaissance sampling is not presented because of the questionable accuracy of the data set as a whole. Prolonged storage of the samples may have compromised the validity of the laboratory analysis. Breakdown or changes in organic compounds can occur with time. Some of the samples were stored for more than a year at temperatures between -17.8 °C and 0 °C. Egg samples were discarded prior to analysis because they were stored an excessively long time at above 0 °C However, frozen tissue samples were thought to be stable and therefore analysis was completed. Although preliminary evaluation of the data does not indicate that levels of DDT and its metabolites, DDE and DDD, were substantially different from results of other studies, interpretation is deferred until data from additional samples collected in 1988 and 1989 are available for comparison. The combined data will be presented in a forthcoming report on the detailed study in progress.

Statistical Analysis of Constituent Concentrations

Correlation of selenium and boron with other trace elements or with more routinely measured constituents might be helpful in determining their distribution and in understanding the mechanisms that produced the elevated levels. Regression analysis can be used to evaluate the relation among influential variables in order to use these models for predictive purposes and to make inferences about the variables of interest. The data collected by the California Regional Water Quality Control Board afforded an opportunity by virtue of the size of the data set (119 samples) to examine the relation among constituents detected in drainwater.

Regression analysis of selenium and dissolved-solids concentrations was done using log base 10 normalized data. The data plot, regression equation, and analysis of variance are presented in figure 18. The $100 \times r^2$ value of 70.5 is evidence of a strong correlation between selenium and dissolved solids. Thus, it is apparent that drains having high dissolved-solids concentrations also have high selenium concentrations. Of the eight drains sampled during the current investigation, tile drain 6, which had a selenium concentration of 300 µg/L, also had the highest dissolved-solids concentration, 26,000 mg/L. The high selenium concentration of 267 µg/L from the data collected by the Regional Board had an accompanying dissolved-solids concentration of 25,000 mg/L. The correlation of selenium with dissolved solids also was observed in the west side of the San Joaquin Valley. Deverel and Millard (1988) determined that the correlation coefficient between the natural logarithms of selenium and specific conductance (a measure of dissolved-solids concentration) was 0.79 for 68 samples collected in the alluvial-fan zone.

Correlation between selenium and dissolved solids does not hold true for the Salton Sea, where evaporation produces the high salinity. Other processes--such as microbial reduction to Se° (elemental and relatively insoluble selenium), volatilization, or bioaccumulation--remove the selenium and concentrate it in the bottom sediments (Oremland and others, 1989). The evaporative processes in the soil, which contribute to the high salinity in tile drains at some of the fields, also apparently are concentrating the selenium. Some generalizations can be drawn from comparisons of selenium concentrations and the quantity of discharge in the tile drains. Elevated selenium concentrations occur only with lower discharges. However, many of the lower discharges also have low selenium concentrations; thus, there is no indicated correlation between discharge and chemical concentration.

Regression analysis also was done between boron and dissolved-solids concentrations. The plot of the log base 10 normalized data is shown in figure 19. The $100 \times r^2$ value for the boron and dissolved-solids regression is 77.2, compared with 70.5 for selenium and dissolved solids.

Boron concentration in the Salton Sea composite sample was the highest of the reconnaissance, 11,000 µg/L, substantiating that although similar processes contribute to the high salinity, high selenium, and high boron in the tile-drain effluent, the mechanisms that affect the concentration of selenium in the Salton Sea are different from those that control the concentrations of boron and dissolved solids.

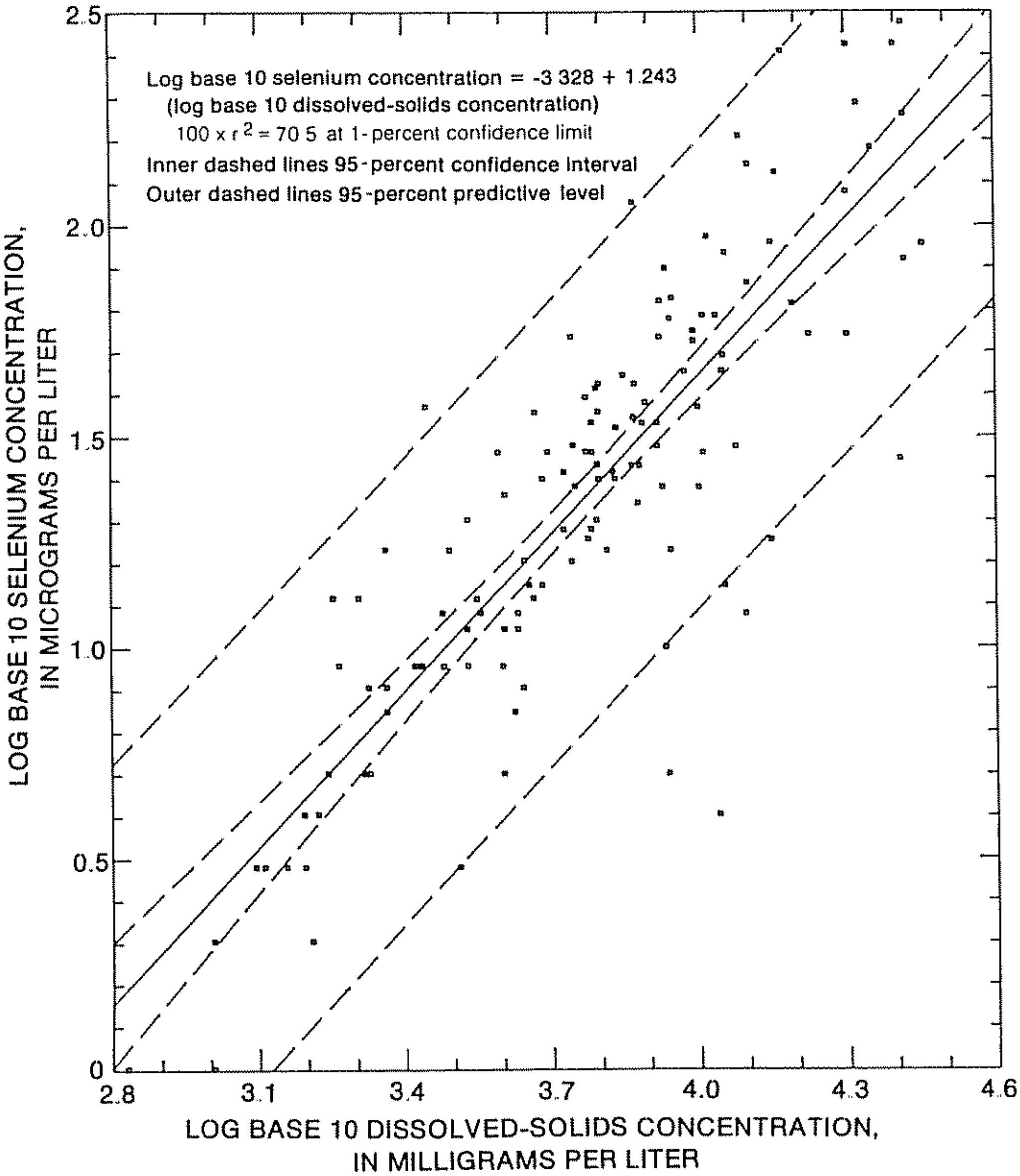

FIGURE 18.--Relation between concentrations of selenium and dissolved solids in samples from tile drains in the Salton Sea area, 1986. Data from California Regional Water Quality Control Board, Colorado River Basin Region (P.A. Gruenberg, written communication, 1986)

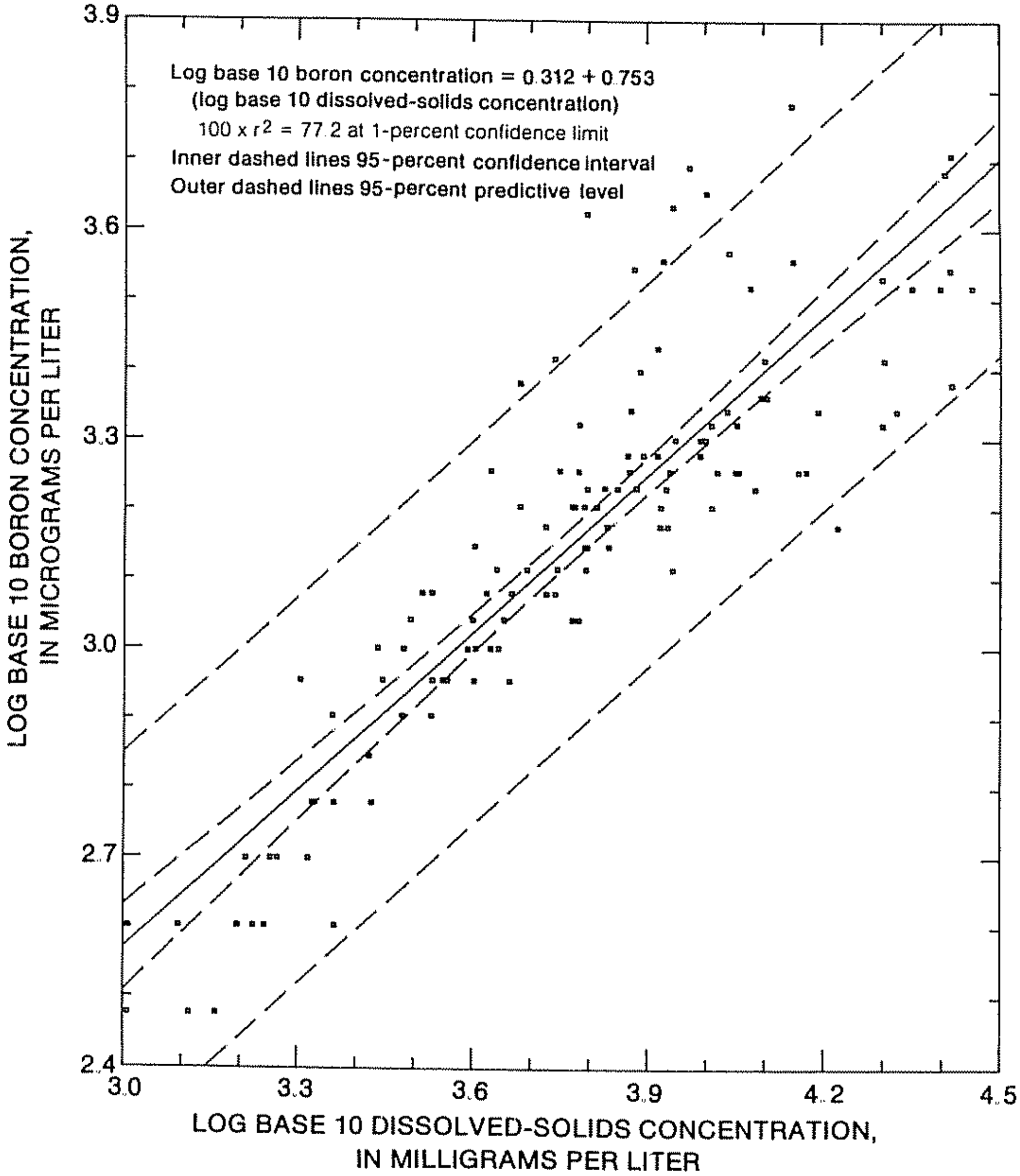

FIGURE 19.--Relation betweeen concentrations of boron and dissolved solids in samples from tile drains in the Salton Sea area, 1986. Data from California Regional Water Quality Control Board, Colorado River Basin Region (P.A. Gruenberg, written communication, 1986).

Variation and Correlation of Selenium Among Substrates

The substrates sampled for selenium concentration include water, bottom sediments, aquatic vegetation, benthic invertebrates, fish, and bird tissues. The pathway leading to presence of selenium in the tissues of the birds and fish at the Salton Sea National Wildlife Refuge begins with elemental concentrations of selenium in the inflowing water to the Salton Sea. Selenium concentrations in inflows are the result of aqueous-sediment phase interactions, which include oxidation/reduction reactions, biological transformations, and physical transport phenomena (such as deposition and suspension), that also occur in the collector drains and rivers tributary to the Salton Sea.

Selenium detected in the bottom sediments of collector drains and the New and Alamo Rivers probably is contributed by tailwater runoff and especially by tile-drain effluent. Although the flow in the drainage ditches varies from clear to turbid depending on water velocity and tailwater contribution, the tile-drain effluent is virtually sediment free. Water in the New and Alamo Rivers at the outlets to the Salton Sea often has a "milk chocolate" appearance due to the sediment load. At a flow rate of 1.6 ft/s in the New River (Setmire, 1984, p. 31), most of the suspended sediment in the river is in the less-than-62-micrometer fraction. Analyses of water samples collected during the reconnaissance study at the New and Alamo Rivers outlet sites were for dissolved-phase selenium, and thus the contribution to the Salton Sea of selenium adsorbed on the fine suspended sediments was not measured. The concentration of dissolved selenium in the water at the New and Alamo Rivers outlets was 4 and 9 $\mu g/L$, respectively. The corresponding selenium concentrations in bottom sediments of 0.6 and 0.4 mg/kg, although low for bottom sediments, are about 100 times higher than the selenium concentration in water. Control-site selenium concentrations at the East Highline Canal were 0.9 mg/kg in the bottom sediments and 2 $\mu g/L$ in the water (California Regional Water Quality Control Board, written commun., 1986).

Processes affecting selenium concentrations in the Salton Sea (1 $\mu g/L$, water; 3.3 mg/kg, bottom sediments) are different from those in the rivers and drains. The hydrologic regimen of the Salton Sea has produced an environment conducive to the development of density stratifications and anaerobic conditions, especially in the shallow southern part. These conditions partially control the partitioning and movement of selenium in the delta area.

There are several processes by which selenium can be removed from water and concentrated in the sediments. One possible mechanism for the removal of selenium in the water of the delta area is by incorporation of selenium into the phytoplankton. These particles can settle in the anoxic zone where they degrade, releasing organic selenide (Cutter, 1982). Cook and Bruland (1987) sampled the Salton Sea and observed a strong density gradient at depths of 1 to 6 meters (3 to 20 feet) that caused complete oxygen depletion at depths below 8 meters (26 feet), where hydrogen sulfide was detected. Of the total selenium content, they found that 58 to 81 percent was in the -II or 0 oxidation states. Selenite constituted 33 percent of the selenium in the oxic surface waters but less than 1 percent in anoxic bottom water. Selenate was not detected in either the oxic or anoxic surface waters. Concentrations of dimethyl selenide (DMSe) increased with depth and constituted 2 to 11 percent of the total selenium.

According to Cutter (1982), "Selenium can also undergo oxidation-reduction reactions, which transform it from one dissolved species to another or to insoluble forms such as elemental selenium or metal selenides (this may be one mechanism that removes selenate and selenite from the anoxic zone)." These processes in the Salton Sea would be seasonally dependent on climatic conditions for their occurrence. This cycling also would be interconnected to cycling of specific microorganisms. Cook and Bruland (1987) concluded that the "increasing concentrations of DMSe with depth in the Salton Sea most likely results from the degassing of DMSe from the surface layers, combined with accumulation in deeper waters due to restricted exchange between surface and deep waters. The absence of selenate in surface waters is particularly surprising since selenate is the thermodynamically predicted form in oxygenated waters." According to Cook and Bruland (1987), "Selenate delivered to the Salton Sea has undergone reductive incorporation by organisms. The presence of selenite may be explained by the oxidation of reduced organic selenium compounds to selenite in the oxygenated upper 4 meters of the water column." As an example of the potential losses of selenium from volatilization, Cook and Bruland (1987) calculated that selenium losses due to outgassing of DMSe in the Kesterson Ponds were as high as 30 percent of the total selenium introduced into the ponds by the San Luis Drain. The actual amounts lost would vary seasonally with temperature.

Selenium removal and concentration in the bottom sediments also might be due to the activity of microorganisms. Microorganisms have been shown to be effective agents in concentrating metals from solution.

This concentration occurs at the sediment-water interface under reducing conditions. The microorganisms can metabolize soluble selenium salts with the formation of elemental selenium in the cells (Cutter, 1982; Cook and Bruland, 1987).

SUMMARY

The Salton Sea study is one of nine reconnaissance investigations begun in 1986 to determine if irrigation drainage from Department of Interior-sponsored irrigation projects has caused or has the potential to cause substantial harmful effects on humans, fish, or wildlife, or to reduce the suitability of water for beneficial uses. The selenium toxicity problems at Kesterson National Wildlife Refuge generated the interest and impetus to investigate other areas receiving irrigation drainage from agricultural water supplied by the Department of the Interior. The Salton Sea National Wildlife Refuge is affected by irrigation drainage. The Imperial County Health Department has established a health advisory limiting the consumption of fish caught in the Salton Sea to 4 ounces every 2 weeks. This advisory is based on selenium concentrations in fish from the Salton Sea that exceeded 2.0 μg/g wet weight (8 μg/g dry weight).

Selenium is the main element of concern in the Salton Sea area. Results of the Salton Sea reconnaissance investigation indicate that selenium concentrations in the irrigation drainage of the Imperial Valley and in the biota of the Salton Sea area are at levels that could cause physiological harm to fish and wildlife. In water, elevated selenium concentrations are restricted to tile-drain effluent. The maximum detected concentration was 300 μg/L in tile drain 6. The minimum concentration was 1 μg/L for a composite sample collected in the Salton Sea. Median selenium concentration at the 12 Department of Interior reconnaissance water-sampling sites was 19 μg/L. In 119 samples collected by the California Regional Water Quality Control Board, the median selenium concentration was 25 μg/L. Selenium and boron displayed strong correlations with dissolved-solids concentrations ($100 \times r^2$ = 70.5 and 77.2, respectively).

Selenium concentrations were determined for 17 bottom-sediment samples collected in drains and rivers in the Coachella and Imperial Valleys. The highest selenium concentration, 3.3 mg/kg, was detected in a composite sample from the Salton Sea, and the lowest concentration, 0.1 mg/kg, was detected at the Whitewater River upstream from Highway 111. The median selenium concentration in bottom sediments was 0.7 mg/kg, which is within the baseline range for soils in the Western United States.

The 3.3 mg/kg selenium concentration in the bottom sediment of the Salton Sea had a corresponding selenium concentration in the water of 1 μg/L, the lowest selenium concentration detected during the reconnaissance sampling. Apparently, some mechanism in the delta area is removing selenium from the water and concentrating it in the bottom sediment. This accumulation of selenium in bottom sediment seems to be the first stage of selenium incorporation into the food chain. Bioaccumulation of selenium is responsible for the elevated levels of the element found in the biota.

In fish from the Salton Sea, selenium levels ranged from 3.5 to 20 μg/g for tilapia and corvina; the mean concentration, 10.5 μg/g, exceeds the health advisory level of 8 μg/g dry weight for human consumption of fish. These concentrations might not have the same deleterious effects in a saline system that they would have in a freshwater system. The levels of selenium observed in samples of birds have been linked to reproductive problems at other drainwater study sites. Selenium was detected at concentrations as high as 27 and 42 μg/g in black-necked stilts and cormorants. However, the biological effects of selenium at these concentrations in the Salton Sea area have not been documented.

Boron concentrations in water were elevated in comparison with the 750 μg/L criterion for irrigation of sensitive crops. None of the sampled water, however, was destined for irrigation. The highest boron concentration, 11,000 μg/L, is attributable to evaporative concentration in the Salton Sea.

Elevated concentrations of other elements detected during the reconnaissance are not directly attributable to irrigation drainage. Manganese was detected at concentrations as high as 2,900 μg/L in the reconnaissance tile-drain samples, and as high as 7,700 μg/L in the California Regional Water Quality Control Board's tile-drain samples. These high manganese concentrations probably result from geothermal activity, which is prominent in the area near the southern end of the Salton Sea. Manganese concentrations in the New and Alamo Rivers and in the Salton Sea were not elevated. Zinc concentrations ranged from 20 to 70 μg/L and did

not exceed the U.S. Environmental Protection Agency criteria (120 μg/L for freshwater and 95 μg/L for saltwater) in any of the water samples.

Elevated concentrations (higher than baseline maximum for soils of the Western United States) of nickel, chromium, and zinc detected in bottom sediment of the Whitewater River probably are the result of industrial contamination, and are not associated with irrigation drainage. Levels of these elements found in biota do not indicate exposure or bioaccumulation.

Organochlorine pesticide residues in bottom sediment are at concentrations approaching those detected in 1977. Although no DDT was detected in the samples (DDT was banned in the United States in 1972), its metabolites, DDD and DDE, were found at concentrations as high as 64 μg/kg (DDE) in bottom sediment of the Alamo River at its outlet, and as high as 24 μg/kg (DDD) in bottom sediment of the New River at the international boundary. Because these compounds are strongly hydrophobic, concentrations detected in water usually are low. These compounds are mobilized by tailwater runoff, which carries soils with the sorbed metabolites, or by resuspension of sediment in the collector drains and rivers.

Other organochlorine pesticide residues were detected in bottom sediment during the reconnaissance. Chlordane, a cyclodiene insecticide, was found in the New River at the international boundary; toxaphene, an insecticide heavily used on cotton in the 1970's, was detected in Trifolium Drain 4; and methoxychlor, a DDT analogue also used to control ectoparasites and other insects, was detected in Vail Drain 4.

Water samples were collected from eight tile drains in the Imperial Valley to determine the concentrations of volatile organic compounds used as fungicides. No such compounds were detected. Few organophosphorus and other pesticide residues were detected in water samples collected in the New and Alamo Rivers at the outlets to the Salton Sea, the Salton Sea (composite, site 15), and Trifolium Drain 1.

Boron is present in the drains, and it concentrates by evaporation in the Salton Sea. Sago pondweed in the Trifolium/Vail Drains had a boron concentration of 370 μg/g in the whole plant, which is at a level that might cause reproductive effects if used as a food source. Ruddy and shoveler ducks, which had boron concentrations ranging from less than 20 to 180 μg/g in their livers, also may be accumulating boron.

Mercury concentration in fish-eating birds such as cormorants and great blue herons ranged from 7.6 to 49 μg/g, with a mean of 23.6 μg/g. Concentrations in fish were below 85th-percentile concentrations for the National Contaminant Biomonitoring Program, indicating a mercury source outside the study area.

DDT metabolites have been detected in sediment and wildlife of the Salton Sea National Wildlife Refuge for more than a decade. On the basis of previous studies in the area, DDE may be bioaccumulating in certain waterfowl tissues.

Several contaminants have been detected in the biota and in the water and bottom sediment of the Salton Sea area at levels that have caused deleterious effects to wildlife in other areas. The Salton Sea National Wildlife Refuge has coexisted with irrigated agriculture in the Imperial Valley for more than 50 years, but during that time no nesting or reproductive studies have been completed to document any deleterious effects of irrigation drainage to the wildlife of the area. Contaminants have been detected at levels of concern, but their effects on fish and wildlife in the Salton Sea area are unknown.

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Table 16.–*Trace-element concentrations in biota, Salton Sea area, 1986-87*

[Concentrations in micrograms per gram, dry weight. <, less than indicated detection limit; --, no data. Results for each composite sample are shown separately]

Sample type	Arsenic		Boron		Cadmium		Chromium		Copper		Iron		Lead		Magnesium	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
Site B1 New River at Rio Bend																
AQUATIC VEGETATION																
Sago pondweed	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	3.1	--	48	--	0.53	--	<0.8	--	8.9	--	11,000	--	<8	--	8,900	--
	.85	--	41	--	.42	--	<.8	--	7.2	--	7,200	--	<8	--	3,400	--
INVERTEBRATES																
Asiatic river clams	3.1	0.58	52	--	1.0	<0.4	1.0	--	29	6.35	340	722	<8	<8	1,400	--
	4.7	--	65	--	1.3	--	1.3	--	34	--	740	--	<8	--	2,200	--
	6.0	--	71	--	1.4	--	1.4	--	63	--	700	--	<8	--	2,400	--
Crayfish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FORAGE FISH																
Mosquitofish	<.5	--	<20	--	<.4	--	<.8	--	<2	--	100	--	<8	--	1,200	--
Sailfin mollies	.73	--	<20	--	<.4	--	<.8	--	6.3	--	330	--	<8	--	1,600	--
	.75	--	<20	--	<.4	--	<.8	--	4.5	--	500	--	<8	--	1,600	--
Redfin shiner	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilapia	<.5	--	<20	--	<.4	--	<.8	--	<2	--	47	--	<8	--	840	--
	.75	--	<20	--	<.4	--	<.8	--	<2	--	140	--	<8	--	1,100	--
Mudsucker	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corvina (muscle)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coot (liver)	<.5	--	52	--	.71	--	<.8	--	53	--	6,600	--	--	--	710	--
Cormorant (liver)	<.5	--	<20	--	.88	--	.88	--	20	--	1,200	--	--	--	810	--
Cattle egret (liver)	--	<.5	--	--	--	1.4	--	--	35.4	--	--	2,490	--	<8	--	--
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--MIGRATORY																
Shoveler (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gull (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ruddy duck (liver)	<.5	--	180	--	.62	--	<.8	--	180	--	1,900	--	<8	--	680	--

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Manganese 1986	Manganese 1987	Mercury 1986	Mercury 1987	Molybdenum 1986	Molybdenum 1987	Nickel 1986	Nickel 1987	Selenium 1986	Selenium 1987	Thallium 1986	Thallium 1987	Vanadium 1986	Vanadium 1987	Zinc 1986	Zinc 1987
Site B1 New River at Rio Bend--Continued																
AQUATIC VEGETATION																
Sago pondweed	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	200	--	0.26	--	18	--	6.1	--	0.43	--	--	--	48	--	41	--
	200	--	.20	--	<4	--	5.2	--	.20	--	--	--	7.1	--	39	--
INVERTEBRATES																
Asiatic river clams	31	--	.42	<0.1	<4	<4	<3.2	65	4.8	0.71	--	<0.5	<4	<4	180	7.03
	71	--	.61	--	<4	--	<3.2	--	5.1	--	--	--	<4	--	250	--
	78	--	.62	--	<4	--	3.4	--	6.2	--	--	--	<4	--	230	--
Crayfish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FORAGE FISH																
Mosquitofish	21	--	.18	--	<4	--	<3.2	--	5.4	--	--	--	<4	--	120	--
Sailfin mollies	35	--	.19	--	<4	--	<3.2	--	6.7	--	--	--	<4	--	92	--
	42	--	.18	--	<4	--	3.4	--	7.7	--	--	--	<4	--	70	--
Redfin shiner	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilapia	9.7	--	.16	--	<4	--	<3.2	--	8.0	--	--	--	<4	--	44	--
	11	--	.15	--	<4	--	<3.2	--	10	--	--	--	<4	--	64	--
Mudsucker	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corvina (muscle)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coot (liver)	11	--	.68	--	<4	--	<3.2	--	16	--	--	--	<4	--	190	--
Cormorant (liver)	19	--	7.6	--	<4	--	<3.2	--	21	6.7	--	--	<4	--	96	--
Cattle egret (liver)	--	--	--	.17	--	<4	--	<3.2	--	7.4	--	.9	--	.9	--	149
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--MIGRATORY																
Shoveler (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gull (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ruddy duck (liver)	19	--	.28	--	<4	--	<3.2	--	19	--	--	--	<4	--	130	--

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Arsenic 1986	Arsenic 1987	Boron 1986	Boron 1987	Cadmium 1986	Cadmium 1987	Chromium 1986	Chromium 1987	Copper 1986	Copper 1987	Iron 1986	Iron 1987	Lead 1986	Lead 1987	Magnesium 1986	Magnesium 1987
Site B2 Whitewater River delta																
AQUATIC VEGETATION																
Sago pondweed	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	2.4	–	40	–	<0.4	–	<0.8	–	5.8	–	3,900	–	<8	–	4,700	–
INVERTEBRATES																
Asiatic river clams	11	–	66	–	<.4	–	1.3	–	24	–	4,500	–	<8	–	2,900	–
Crayfish	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
FORAGE FISH																
Mosquitofish	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sailfin mollies	.77	–	<20	–	<.4	–	<.8	–	10	–	4,200	–	<8	–	3,800	–
Redfin shiner	–	<.5	–	–	<.4	–	–	–	–	4.59	–	387	–	<8	–	–
Tilapia	2.6	–	<20	–	.5	–	<.8	–	5.7	–	7,100	–	<8	–	5,000	–
	1.1	–	<20	–	<.4	–	<.8	–	<2	–	5,600	–	8	–	310	–
Mudsucker	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Corvina (muscle)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	.73	–	<20	–	1.8	–	1.8	–	21	–	1,600	–	<8	–	940	–
Coot (liver)	<.5	–	22	–	.44	–	<.8	–	51	–	4,800	–	<8	–	830	–
Cormorant (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cattle egret (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Great blue heron (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER BIRDS--MIGRATORY																
Shoveler (liver)	<.5	–	40	–	.46	–	<.8	–	42	–	2,800	–	<8	–	840	–
Gull (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ruddy duck (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Manganese		Mercury		Molybdenum		Nickel		Selenium		Thallium		Vanadium		Zinc	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
Site B2 Whitewater River delta--Continued																
AQUATIC VEGETATION																
Sago pondweed	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	150	--	0.16	--	<4	--	7.5	--	0.15	--	--	<0.5	5.1	--	40	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
INVERTEBRATES																
Asiatic river clams	120	--	.56	--	6.8	--	3.4	--	5.4	--	--	--	5.3	--	140	--
Crayfish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FORAGE FISH																
Mosquitofish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sailfin mollies	67	--	.15	--	<4	--	<3.2	--	3.7	--	--	--	7.3	--	64	--
Redfin shiner	--	--	--	0.16	--	<4	--	<3.2	--	4.7	--	<.5	--	<4	--	163
Tilapia	120	--	.22	--	<4	--	4.7	--	6.3	--	--	--	16	--	50	--
	12	--	.18	--	<4	--	<3.2	--	3.5	--	--	--	<4	--	8.7	--
Mudsucker	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corvina (muscle)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	17	--	.72	--	<4	--	<3.2	--	19	--	--	--	<4	--	140	--
Coot (liver)	13	--	.27	--	4.5	--	<3.2	--	14	--	--	--	<4	--	210	--
Cormorant (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cattle egret (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--MIGRATORY																
Shoveler (liver)	18	--	2.2	--	4.4	--	<3.2	--	17	----		--	<4	--	120	--
Gull (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ruddy duck (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Arsenic 1986	Arsenic 1987	Boron 1986	Boron 1987	Cadmium 1986	Cadmium 1987	Chromium 1986	Chromium 1987	Copper 1986	Copper 1987	Iron 1986	Iron 1987	Lead 1986	Lead 1987	Magnesium 1986	Magnesium 1987
Site B3 Trifolium/Vail Drains																
AQUATIC VEGETATION																
Sago pondweed	2.1	–	370	–	0.60	–	<0.8	–	5.2	–	4,600	–	<8	–	8,300	–
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	2.7	–	110	–	.60	–	<.8	–	<2	–	4,600	–	<8	–	4,000	–
	.97	–	64	–	.48	–	<.8	–	4.3	–	2,200	–	<8	–	4,500	–
INVERTEBRATES																
Asiatic river clams	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Crayfish	–	1.7	–	–	–	0.55	–	–	–	113	–	1,860	–	<8	–	–
FORAGE FISH																
Mosquitofish	<.5	–	25	–	<.4	–	<.8	–	2.7	–	160	–	<8	–	1,500	–
	<.5	–	<20	–	<.4	–	<.8	–	2.8	–	100	–	<8	–	1,300	–
Sailfin mollies	.69	–	26	–	<.4	–	<.8	–	8.8	–	300	–	<8	–	1,600	–
Redfin shiner	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tilapia	.99	–	<20	–	<.4	–	<.8	–	<2	–	300	–	387	–	1,700	–
	.67	–	24	–	<.4	–	<.8	–	3.7	–	270	–	<8	–	1,700	–
Mudsucker	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Corvina (muscle)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	–	–	<20	–	–	–	–	–	–	–	–	–	–	–	–	–
Coot (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cormorant (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cattle egret (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Great blue heron (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER BIRDS--MIGRATORY																
Shoveler (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gull (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ruddy duck (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Manganese		Mercury		Molybdenum		Nickel		Selenium		Thallium		Vanadium		Zinc	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
Site B3 Trifolium/Vail Drains--Continued																
AQUATIC VEGETATION																
Sago pondweed	1,200	--	0.25	--	<4	--	8.3	--	1.1	--	--	--	11	--	35	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	170	--	.30	--	<4	<4	11	--	.3	--	--	--	18	--	22	--
	50	--	.24	--	<4	--	7	--	.2	--	--	--	9	--	25	--
INVERTEBRATES																
Asiatic river clams	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Crayfish	--	--	--	<0.1	--	<4	--	<3.2	--	3.7	--	1.0	--	5.62	--	101
FORAGE FISH																
Mosquitofish	29	--	.21	--	<4	--	<3.2	--	16	--	--	--	<4	--	100	--
	16	--	.18	--	<4	--	<3.2	--	7.3	--	--	--	4.1	--	100	--
Sailfin mollies	42	--	.19	--	<4	--	<3.2	--	9.8	--	--	--	<4	--	70	--
Redfin shiner	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilapia	39	--	.17	--	<4	--	<3.2	--	12	--	--	--	4.5	--	47	--
	17	--	.19	--	<4	--	<3.2	--	9.3	--	--	--	5.3	--	79	--
Mudsucker	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corvina (muscle)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Coot (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cormorant (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cattle egret (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS--MIGRATORY																
Shoveler (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Gull (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ruddy duck (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Arsenic 1986	Arsenic 1987	Boron 1986	Boron 1987	Cadmium 1986	Cadmium 1987	Chromium 1986	Chromium 1987	Copper 1986	Copper 1987	Iron 1986	Iron 1987	Lead 1986	Lead 1987	Magnesium 1986	Magnesium 1987
Site B4 New River delta																
AQUATIC VEGETATION																
Sago pondweed	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	3.5	–	61	–	0.43	–	<0.8	–	9.4	–	4,100	–	<8	–	3,600	–
	4.6	–	130	–	.51	–	<.8	–	13	–	7,300	–	<8	–	4,000	–
INVERTEBRATES																
Asiatic river clams	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Crayfish	–	2.2	–	–	–	0.4	–	–	–	68.7	–	991	–	<8	–	–
FORAGE FISH																
Mosquitofish	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sailfin mollies	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Redfin shiner	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tilapia	1.2	–	20	–	<.4	–	<.8	–	<2	–	790	–	–	–	2,000	–
	.84	–	22	–	.44	–	<.8	–	7.8	–	350	–	–	–	1,200	–
Mudsucker	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Corvina (muscle)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	.5	–	<20	–	1.3	–	1.3	–	20	–	–	–	–	–	670	–
Coot (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cormorant (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cattle egret (liver)	–	<.5	–	–	–	.58	–	–	–	15.7	–	–	–	–	–	–
Great blue heron (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
WATER BIRDS--MIGRATORY																
Shoveler (liver)	<.5	–	110	–	2.0	–	2.0	–	110	–	3,900	–	<8	–	780	–
	<.5	–	50	–	1.9	–	1.9	–	25	–	1,600	–	<8	–	760	–
	<.5	–	48	–	.44	–	<.8	–	13	–	5,100	–	<8	–	880	–
Gull (liver)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ruddy duck (liver)	<.5	–	150	–	<.4	–	<.8	–	150	–	3,800	–	<8	–	700	–

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Manganese 1986	Manganese 1987	Mercury 1986	Mercury 1987	Molybdenum 1986	Molybdenum 1987	Nickel 1986	Nickel 1987	Selenium 1986	Selenium 1987	Thallium 1986	Thallium 1987	Vanadium 1986	Vanadium 1987	Zinc 1986	Zinc 1987
Site B4 New River delta--Continued																
AQUATIC VEGETATION																
Sago pondweed	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	170	--	0.21	--	<4	--	6.4	--	0.22	--	--	--	13	--	40	--
	310	--	.25	--	5.0	--	9.0	--	.77	--	--	--	31	--	37	--
INVERTEBRATES																
Asiatic river clams	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Crayfish	--	--	--	<0.1	--	<4	--	<3.2	--	2.5	--	0.9	--	<4	--	105
FORAGE FISH																
Mosquitofish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sailfin mollies	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Redfin shiner	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilapia	72	--	.14	--	<4	--	<3.2	--	17	--	--	--	6.6	--	45	--
	39	--	.19	--	<4	--	<3.2	--	4.3	--	--	--	<4	--	25	--
Mudsucker	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Corvina (muscle)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS-RESIDENTS																
Black-necked stilt (liver)	15	--	1.2	--	<4	--	9.2	--	27	--	--	--	<4	--	130	--
Coot (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cormorant (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cattle egret (liver)	--	--	--	0.10	--	<4	--	--	--	5.2	--	.9	--	<4	--	77.6
Great blue heron (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
WATER BIRDS-MIGRATORY																
Shoveler (liver)	26	--	3.7	--	7.8	--	<3.2	--	26	--		--	<4	--	220	--
	13	--	11	--	<4	--	4.0	--	20	--	--	--	<4	--	120	--
	13	--	.52	--	6.5	--	<3.2	--	8.3	--	--	--	<4	--	180	--
Gull (liver)	--	--	--	--	--	--	--	--	--	14	--	--	--	--	--	--
Ruddy duck (liver)	17	--	1.4	--	<4	--	<3.2	--	27	--	--	--	<4	--	140	--

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Arsenic 1986	Arsenic 1987	Boron 1986	Boron 1987	Cadmium 1986	Cadmium 1987	Chromium 1986	Chromium 1987	Copper 1986	Copper 1987	Iron 1986	Iron 1987	Lead 1986	Lead 1987	Magnesium 1986	Magnesium 1987
Site B5 Alamo River delta																
AQUATIC VEGETATION																
Sago pondweed	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	2.8	--	72	--	0.50	--	<0.8	--	12	--	6,900	--	<8	--	9,100	--
	1.1	--	51	--	.41	--	<.8	--	8.3	--	2,700	--	<8	--	290	--
INVERTEBRATES																
Asiatic river clams	--	<0.5	--	--	--	<0.4	--	--	--	5.17	--	536	--	<8	--	--
Crayfish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FORAGE FISH																
Mosquitofish	<.5	--	<20	--	<.4	--	<.8	--	2.3	--	270	--	<8	--	1,300	--
	<.5	--	<20	--	<.4	--	<.8	--	3.0	--	180	--	<8	--	1,100	--
Sailfin mollies	.76	--	22	--	.44	--	<.8	--	11	--	180	--	<8	--	1,100	--
Redfin shiner	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilapia	1.3	2.7	21	--	.42	<.4	<.8	--	<2	<2	210	27.7	<8	<8	1,400	--
	1.3	--	<20	--	.42	--	<.8	--	<2	--	260	--	<8	--	1,800	--
	2.6	--	42	--	<.4	--	<.8	--	2.5	--	190	--	<8	--	1,400	--
Mudsucker	--	1.1	--	--	--	<.4	--	--	--	2.23	--	84.9	--	<8	--	--
Corvina (muscle)	3.9	--	<20	--	.48	--	<.8	--	3.7	--	83	--	<8	--	1,100	--
WATER BIRDS--RESIDENTS																
Black-necked stilt (liver)	<.5	--	36	--	3.4	--	3.4	--	25	--	1,200	--	--	--	710	--
Coot (liver)	1.0	--	47	--	.54	--	<.8	--	32	--	4,600	--	--	--	600	--
Cormorant (liver)	<.5	<.5	25	--	.40	2.8	<.8	--	8.5	16.3	1,800	2,130	<8	<8	570	--
Cattle egret (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Great blue heron (liver)	--	<.5	--	--	--	<.4	--	--	--	22.3	--	5,720	--	<8	--	--
WATER BIRDS--MIGRATORY																
Shoveler (liver)	.50	--	23	--	3.4	--	3.4	--	62	--	4,900	--	<8	<8	880	--
Gull (liver)	--	<.5	--	--	--	2.3	--	--	--	9.07	--	2,200	--	<8	--	--
Ruddy duck (liver)	<.5	--	<20	--	<.4	--	<.8	--	7.5	--	100	--	<8	--	950	--

Table 16.--*Trace-element concentrations in biota, Salton Sea area, 1986-87*--Continued

Sample type	Manganese		Mercury		Molybdenum		Nickel		Selenium		Thallium		Vanadium		Zinc	
	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987	1986	1987
Site B5 Alamo River delta--Continued																
AQUATIC VEGETATION																
Sago pondweed	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
EMERGENT WETLAND PLANTS																
Bulrush/Sorrel	130	--	0.22	--	<4	--	8.0	--	0.74	--	--	--	23	--	5.0	--
	170	--	.19	--	<4	--	6.1	--	.2	--	--	--	5.9	--	28	--
INVERTEBRATES																
Asiatic river clams	--	--	--	<0.1	--	<4	--	46.7	--	0.67	--	<0.5	--	<4	--	7.06
Crayfish	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FORAGE FISH																
Mosquitofish	30	--	.19	--	<4	--	<3.2	--	7.6	--	--	--	<4	--	99	--
	25	--	.17	--	<4	--	<3.2	--	6.3	--	--	--	<4	--	89	--
Sailfin mollies	44	--	.18	--	<4	--	<3.2	--	11	--	--	--	<4	--	60	--
Redfin shiner	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Tilapia	17	--	.19	<.1	<4	<4	<3.2	<3.2	14	4.3	--	<.5	<4	<4	83	36.2
	13	--	.21	--	<4	--	<3.2	--	12	--	--	--	6	--	77	--
	14	--	.18	--	<4	--	<3.2	--	17	--	--	--	<4	--	41	--
Mudsucker	--	--	--	<.1	--	<4	--	<3.2	--	7.2	--	<.5	--	<4	--	68.2
Corvina (muscle)	12	--	.20	--	<4	--	<3.2	--	20	--	--	--	<4	--	17	--
WATER BIRDS-RESIDENTS																
Black-necked stilt (liver)	16	--	1.8	--	<4	--	12	--	20	--	--	--	<4	--	150	--
Coot (liver)	23	--	.34	--	<4	--	<3.2	--	21	--	--	--	<4	--	120	--
Cormorant (liver)	11	--	49	27.6	<4	<4	<3.2	<3.2	18	42	--	.9	<4	<4	68	87.7
Cattle egret (liver)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Great blue heron (liver)	--	--	--	10.3	--	6.3	--	<3.2	--	15	--	.9	--	10.2	--	69.2
WATER BIRDS-MIGRATORY																
Shoveler (liver)	16	--	4.4	--	4.5	--	<3.2	--	21	--	--	--	<4	--	140	--
Gull (liver)	--	--	--	.13	--	<4	--	<3.2	--	14	--	1.0	--	<4	--	77.7
Ruddy duck (liver)	7.5	--	.14	--	<4	--	<3.2	--	7.0	--	--	--	<4	--	41	--

GPO 786-064/39058